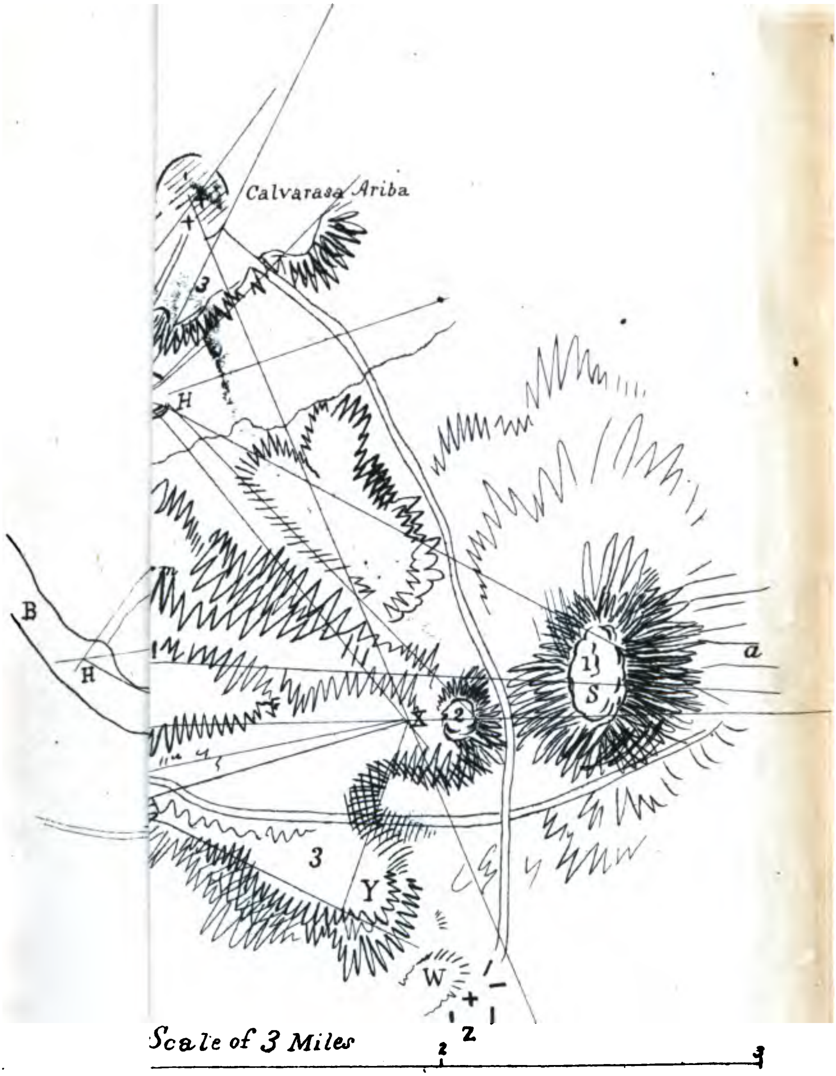

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A TREATISE

ON

MILITARY SURVEYING,

THEORETICAL AND PRACTICAL

INCLUDING

A DESCRIPTION OF SURVEYING INSTRUMENTS.

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PREFACE.

A GREAT portion of the contents of this volume has been taken from the best authorities within reach of the writer, the chief of which are Salneuve, Lalobbe, and Simms.

The writer has endeavored to present the subject in a simple form, that it may be readily comprehended by every one who is liable to be called upon to furnish a sketch of a portion of country.

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MILITARY SURVEYING.

CHAPTER I.

The ordinary maps, upon which are found the positions of the principal towns, the location of the great routes, the courses of the rivers and canals, and the general form of the country, are sufficient to enable one to follow the operations of a campaign; but they are far from being in sufficient detail for the purposes of him who plans or studies the smaller operations of war. The most detailed maps are essential in these cases, because the merest trail, the most insignificant rivulet, the slightest undulation of the ground, may for a time become of the greatest importance, either for the offensive or for the defensive. The preparation of such maps belongs to military topography, and it is evident that it is a subject of the greatest interest to all the arms of the service.

Topography, confined to these purposes, applies the most simple problems of geometry, rarely has recourse to rectilinear trigonometry, and never employs the

principles of spherical trigonometry. It may be defined as the art of obtaining a detailed representation of a portion of the earth's surface of moderate extent. This representation or map should exhibit the important lines and characteristic objects on the ground, such as the water-courses, the great routes, ordinary roads, and even the trails and footpaths, houses, enclosures, ditches, hedges, walls, etc. In addition, it should indicate the lay of the ground and its undulations, the steepness of its slopes, and the relative heights of the commanding points.

From this it appears that the preparation of the map may be said to be composed of two parts:

1. The projection, in proper relative position, on a plane surface, of the objects enumerated above.

2. Levelling, by means of which we may represent the formations of the ground, the character of the slopes, elevations, depressions, etc.

Memoirs.—As it is impossible to exhibit by graphic representation all essential information in this connection, we are compelled to accompany the map with a descriptive memoir, which, in general terms, presents data upon such points as follow: the kind of roads; their state of repair; the descriptions of bridges; character of the approaches to them; the depth and rapidity of the current of water-courses; the nature of the bottom, whether rocky, sandy, etc.; statistical information as to the number of inhabitants, number of animals, supply of provisions, etc., etc.

When it is required to prepare an accurate representation of a portion of country, it is a problem of *regular topography*, and is performed by the use of the most exact methods and instruments; while, where an approximation is sufficient for the purpose in question, it is a case in irregular surveying. This branch of the subject is the one most interesting and important to officers of infantry and cavalry, because by it a fair and tolerably exact map of the ground may be rapidly made without the aid of instruments, or by the use of such as are simple and portable, some of which indeed may be constructed by the officer himself.

One who understands thoroughly the successive steps of regular surveying, and the instruments used in it, should find the application of his principles to irregular surveying easy. It then seems appropriate to study first the pure, exact processes, in order to become acquainted with the principles of the art; and to learn what degree of approximation we are to expect under a departure from accurate methods, to which we are often compelled to submit.

For these reasons, we first proceed to investigate the subject of regular topography.

The earth is an oblate spheroid, the radius of the equator being $6^{m}974.532\tfrac{339}{1000}$ yards. The polar radius being $6^{m}951.218\tfrac{059}{1000}$ yards, is about 13.25 miles shorter than the equatorial. For our purposes we

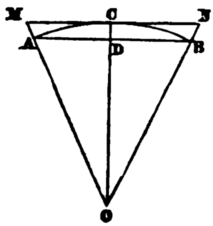


Fig. 1.

may regard the earth as a sphere, and although it is not developable on a plane surface, yet it may be shown that within the narrow limits of topography, no sensible error is committed by regarding the spherical zone as coincident with a plane tangent to the surface of the earth at the middle point. In Fig. 1, A C B represents an arc of a great circle of the earth, 1° in extent, M N the trace of a plane tangent at the middle point, A B the trace of a plane through the extremities of the arc and parallel to M N. The length of the arc is greater than the chord A B, and less than the tangent M N. Let us ascertain the difference between M N and A B:

M C=6.974532 × tang. 30′		A D=6.974532 × sin. 30′	
Log. R	6.8435151	Log. R	6.8435151
Log. tang. 30′	7.9408584	Log. sin. 30′	7.9408419
Log. M C	4.7843735	Log. A D	4.7843570

M C=60865.8 yds.

A D=60863.5 Difference=2.3 yds.

M C−A D=2.3.

Hence we see that the longest line that can be drawn on the surface of the earth within the limits of one degree, differs from its projection on the horizon of its middle point by a quantity less than 4.6 yards, which is quite insignificant in comparison with the length of the line, and may be neglected. Hence within the limits

of topography, which ordinarily is not concerned with so large a portion of the earth's surface as is referred to in the calculation just made, we may regard the line and its projection as equal. Hence if we project all the points of the arc A B on the plane M N, by radii of the earth, it is evident that we shall have, if we conceive these projections to be united, a very exact representation of the surface to be surveyed, and the distances between the points will be horizontal.

If, in order to represent on paper a portion of country, we commence at one point and proceed from detail to detail, fixing each as we attain it, we incur errors, which, continually accumulating, would bring about the most defective results. On this account, the subject of obtaining the horizontal projection of a country is subdivided into two parts, the first consisting in the selection and determination, with the greatest accuracy possible, of the most remarkable points, which are called *principal or primary points*. The second consists in filling in the details. In this part we use the well-determined primary points, and from their positions ascertain and fix the projections of other distinguishing points and characteristic lines.

The principal points having been selected, conceive each of them to be projected by vertical lines on a horizontal plane, and their projections to be joined by right lines. A polygonal figure results, and it is now a question as to the character of the method to be pursued in ascertaining the data necessary to enable

us to construct a similar polygon on paper. Starting

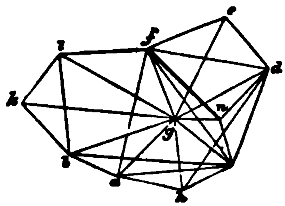


Fig. 2.

from any point, as *a*, it is evident that we can measure *ab*, *bk*, *kl*, etc., and the angles of the polygon. Then assuming on a sheet of paper a given direction for the first side, *ab*, and a position for *a*, let us take the representation of the distance *ab* from the scale of equal parts, and lay it off from *a*; we thus determine *b* on the sheet. Then lay off an angle at *b* equal to the measured angle *a b k*, and draw a line in this direction; on this line lay off a distance from the scale proportional to *b k*; this gives *k*: and so on for other points. This evidently can be done, but it is generally more laborious and less exact than another method; still it may be applied to surveys of small extent.

Generally, in extended surveys, it would be impossible to measure all the distances, owing to the difficulties of the ground, and, fortunately, it is not desirable. The most advantageous method is to apply the principles of trigonometry.

If we conceive the *principal points* to be joined by right lines, we may subdivide the polygonal figure into triangles, in which, as we pass from one to another adjacent, we find a side in common. If, then, we are able to measure the length of one of these lines, and the various angles of the triangles, we have sufficient

data to obtain the lengths of all the other lines by processes of trigonometry.

But, since the object of the survey is to furnish the horizontal projections of the different points, it is necessary to obtain for the given side the horizontal, and not the actual distance measured on the ground; and it is further necessary that the angles used in our calculation should be horizontal angles. Hence we see that neither the angles nor the side which we measure on the ground are correct elements for our subsequent calculation, unless in the very rare case, that within the limits of the survey the ground is a horizontal plane. Both then must be subjected to reductions to the horizon. It may be remarked, however, that all instruments with a graduated horizontal limb for the measurement of angles give an angle reduced already to the horizon, and, consequently, not liable to any correction on this account. Such are the theodolite and the compass.

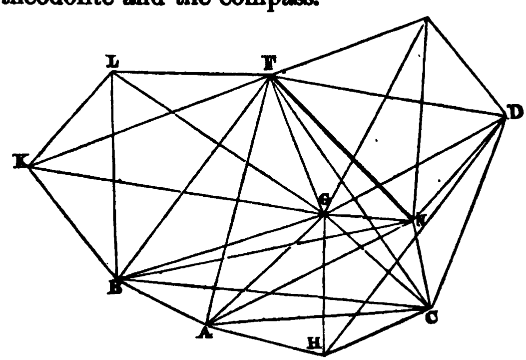


Fig. 8.

Let A B K L, Fig. 3, represent the irregular polygon formed on the plane of projection, by joining the feet of the vertical lines through the principal points, and let us suppose that we have measured directly the side F N, which is called a *base*. Let the angles F, N, in the triangles F N D, F A N, F B N, F G N, be measured; then in each one of these triangles we have one side and all the angles, and by known processes of trigonometry we may find F A, F B, etc., N A, N B, etc., and thus fix the points A, B, etc. Then, for instance, in the triangle F L B, knowing the side F B, and measuring the angles, we may find F L and B L, and so on till all the parts of all the triangles have been determined.

This system admits of numerous verifications, thus: D is first determined from the triangle F N D, and again from the triangle F D G, and the same may be said of almost all the other points.

It is easy, after having obtained these elements, to construct, on paper, a polygon similar to A B K L C, first taking from the scale according to which the map is to be constructed a distance to represent the base F N. This being laid down upon the paper, the positions of the other points are readily found, and the projection of a point, situated at the vertex of two angles, may be regarded as exact.

Base.—We are now able to assign the conditions to be fulfilled by a good base:

1. It should be chosen on level or nearly level

ground, so that it can be easily measured. A straight piece of road would be favorable.

2. From its extremities a number of the principal points should be visible, as this diminishes the number of stations necessary to be occupied for the measurement of angles.

3. It should lie near the middle of the ground to be surveyed. If it were at one extremity, an error committed in the measurement of an angle would run through and accumulate in all the triangles; but when the triangles are arranged about this line nearly symmetrically, or rather equally, the error is more evenly distributed.

It may be desirable in a large survey to measure two bases, one near each extremity. The calculated value of one, deduced by triangulation from the measured value of the other, should very nearly coincide with its direct measure, thus affording an excellent test of accuracy.

The base should be measured with care, and should be of sufficient length, that the triangles into which it enters, as a side, shall not be too acute.

To pass from a base to another of double length.—Let us suppose that, from any circumstances, we have been compelled to adopt a base A B, which is too short: at B

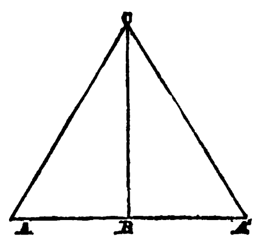


Fig. 4.

erect the perpendicular B C; at A lay off an angle of 60° and draw A C, which is equal to twice A B; for producing A B to A′, making B A′=B A, and joining A′ and C, we have two equal triangles, A B C, A′ B C; and the angles A and A′, being each 60°, the angle A C A′ is also=60°, and the triangle A C A′ is equilateral, and either side of it is equal to twice A B.

The measured base is generally much shorter than the sides of the largest or primary triangles, and often it is necessary to have one or two comparatively small triangles, by means of which we obtain a new base of sufficient length to enter as a side in the larger primary triangles.

The base generally cannot be chosen on level ground; and it may have a continuous or constant slope, or it may consist of parts having different inclinations to the horizon. In the first case, the measured distance on the ground between its extremities and its slope must be taken; in the second, the lengths of the different portions and their respective inclinations, which, by the following process, are reduced to the horizon.

Reduction to the Horizon.—Let A D be a measured distance, and A D′ its projection on the horizon, then from the right-angled triangle, we have A D′=A D cos. *a*.—This formula is very simple;

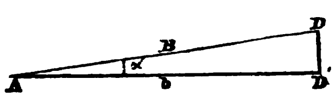


Fig. 5.

but it is preferable to transform it, so that it will give the difference between the measured line and its projection, as cos. $a=1-2$ sin.$^2 \frac{1}{2} a$ we have

$b=B\ (1-2\ \sin.^2 \frac{1}{2}\ a)$ and $B-b=2\ B\ \sin.^2 \frac{1}{2}\ a$.

When a base is measured, the length and inclination of each one of its parts are taken, from which we derive a series of equations as follows, viz.:

$B\ -b\ =2\ B\ \sin.^2 \frac{1}{2}\ a$.

$B'-b'=2\ B'\ \sin.^2 \frac{1}{2}\ a'$, and by addition:

$(B+B'+B''$ etc.$)-(b+b'+b''$ etc.$)=2\ (B \sin.^2 \frac{1}{2}\ a + B'\ \sin.^2 \frac{1}{2}\ a' +$ etc.$)$

Calculating separately the terms in the second member, and adding them together, we have the whole correction to be subtracted, and if this correction is so small that it would not be appreciable on the scale of the map, it may be neglected and the measured base be taken as correct.

The accompanying table furnishes the corrections in feet for a measured distance of 100 feet for all angles of inclination up to 20°, and saves computation by logarithms by the preceding formula.

For a distance of 200 feet, inclination 5°, the reduction would be 0.381 feet multiplied by two; and for any other distance, multiply the ratio of this distance to 100 feet by the correction taken from the table corresponding to the inclination.

Primary Triangulation.—Owing to the defects in instruments, and personal errors of observation, we may expect every measurement of angles and

Angle.	Reduction in ft.	Angle.	Reduction in ft.	Angle.	Reduction in ft.	Angle.	Reduction in ft.	Angle.	Reduction in ft.
° ′		° ′		° ′		° ′		° ′	
3	0.137	6	0.548	9	1.231	12	2.185	15 30	3.637
3 30	0.187	6 30	0.643	9 30	1.371	12 30	2.370	16	3.874
4	0.244	7	0.745	10	1.519	13	2.558	16 30	4.118
4 30	0.308	7 30	0.856	10 30	1.675	13 30	2.763	17	4.370
5	0.381	8	0.973	11	1.837	14	2.970	17 30	4.628
5 30	0.460	8 30	1.098	11 30	2.006	14 30	3.185	18	4.894
						15	3.407	18 30	5.168
								19	5.448
								19 30	5.736
								20	6.031

distances to be in error by a quantity greater or less. The number of errors increases with the number of measurements. It, then, is obviously an advantage to determine the primary points by the minimum number of triangles. As, for the same perimeter, the equilateral triangle has a maximum area, it follows that fewer equilateral than acute or obtuse triangles would be required to cover the area to be surveyed. Hence, in this point of view, the equilateral is the most advantageous form.

But the form of the primary triangles is not a matter of indifference in another respect. Fig. 6. An

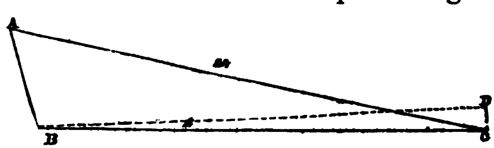


Fig. 6.

error committed in the measurement of the angle B induces a corresponding error in the side C C′, which is evidently more considerable as the angle C is more acute; and for this reason it is an essential rule to choose the principal points, so that the primary triangles shall not contain a very acute or very obtuse angle.

The side C C′ thus affected with error is an element, together with erroneous angles, for the determination of another line, which in turn serves to determine another, and thus an accumulation of error may occur producing the most unsatisfactory results. Hence, if the triangles are very acute, there is not only a greater chance for error in each, but a greater number will be required.

There is still another consideration on this point which is concerned with the length of the sides. These depend upon the extent of the survey, the scale upon which the map is to be executed, and the precision of the instruments used to measure the angles. In a large survey, of course, the sides should be longer than in a small, as the principal points are farther apart.

If the scale is small, an error would be inappreciable, which on a larger one would be very manifest, and the connection existing between the sides and the instrument used for measuring angles may be stated as follows, Fig. 6:

C C′ is the error E in the side A C, arising from an error *b* in the angle B. Call B C=K, E is evidently

a function of b and K. To determine the relation between these quantities, draw C D perpendicular to B C′ produced. Then C D=K tang. b, but C C′ being oblique is longer than C D, hence E>K tang. b, or K is less than $\frac{E}{\text{tang. } b}$. If E is the least distance which is appreciable on the map, according to the scale of construction, then evidently, K should always be less than $\frac{E}{\text{tang. } b}$. K, then, may increase as the scale diminishes, or decrease as the scale is larger, b remaining the same.

It may happen that no discretion can be exercised, but that the nature of the operations demands a certain mean length for K. Then, since tang. $b < \frac{E}{K}$, we may calculate the admissible amount of error in the measurement of angles, and from this the instrument to be used.

Again: supposing the length of K to be obligatory and fixed, and the observer to have no choice of instruments, indeed to have but one, the error of which, b, is known, then we may assert that the sides of the triangles will be affected with error at least equal to K tang. b. Thus we know the degree of confidence to be placed in the result, or we may determine the scale which will make this error inappreciable on the map.

If we regard $\frac{1}{120}$ of an inch to be the smallest appreciable distance on the map, then, when the scale is three inches to one mile, this represents about 15 feet;

hence $K < \frac{15}{\text{tang. } b}$. If the scale is six inches to the mile $K < \frac{15}{2 \text{ tang. } b}$, and if the measuring instrument be a compass for which b is 15′, we have

$$K = 7.5^{\text{ft.}} \times \text{cotang. } 15'$$

$$\begin{aligned} \text{Log. } 7.5 &= 0.8750613 \\ \text{Log. cot. } 15' &= \underline{2.3601799} \\ K = 1719 \text{ feet} \quad &= 3.2352412 \end{aligned}$$

Hence, under these circumstances, this is the maximum limit for the sides; and in a similar manner might be determined the lengths of the sides for the pocket sextant, assuming its error to be 1′, or for the theodolite, in which the error b is generally considerably smaller.

The *principal points* having been determined by the primary triangulation, we are in possession of a number of bases, which serve, in accordance with the same principles, to fix other or secondary points, thus giving rise to another system of triangles, smaller and much more numerous than the first. Indeed, each primary side may be an element in many triangles, which, when calculated, make known the points at their respective vertices, which generally are important details, such as bends in a road or stream, the summits of slight elevations, etc., etc. These triangles are called secondary.

It will be seen further on how the principal points

are plotted on the map, and it is sufficient now to remark that it is not done by the same method that is pursued for secondary points. The latter are plotted by *intersections*, a much quicker method than the one just alluded to. For instance, Fig. 3. Having found by calculation the distances of the secondary point K from the primary points L and B, to plot K, take from the scale, by a pair of dividers, the number of feet in L K; then, with this, a radius, fixing one leg in L, describe an arc of a circle. Take now B K from the scale, and from B as a centre describe another arc, intersecting the former. The common point is the projection of K. Now this common point is evidently most accurately determined when the angle at K is a right angle, and, were it very acute, there would almost certainly be an error in determining the intersection; hence we may say, that the most advantageous form for *secondary* triangles is that right angled at the point whose projection is sought.

These points are also plotted in another way, which perhaps is more often practised, because it saves the calculation of the triangles. As soon as the angles K L B and K B L are measured, lay them off from the map from L and B, and draw L K and B K, the intersection of which gives K; and, equally as before, it is more advantageous to have K a right angle. Acute intersections may still be of value, inasmuch as they may be verified by others, hence they should not be neglected.

Secondary points may be determined in other ways—by measurement, for instance. Having found B, if by any instrument we measure the angle made by B K with any known line through B, as the meridian, or let us take B L, and at the same time pace off the distance of B K, then construct on the paper a line, making with B L an angle equal to the measured angle, and lay off on this line a distance equal to B K, according to the scale, the extremity of this distance is K in projection. This may answer when applied in this manner, that is, starting from a well-determined point, as B; but if we use K, thus determined as a station, for the fixing of another point, and this for another, and so on, indefinitely, each error is added to what previously existed, and accumulates with every successive operation. It is true that the errors might, and generally do, compensate more or less. It is sometimes unavoidably necessary to apply this method; but no means should be neglected for checking error and verifying points, by taking bearings of all well-determined stations whenever it is practicable.

The meridian should be represented on the map. The angles, made by any side of a triangle with it, are called azimuths. The manner in which they are reckoned from the meridian is arbitrary; in astronomy, for the northern hemisphere, they are measured on the horizon, from its south intersection with the meridian of the west, and the limit of value is 360°. They are sometimes distinguished in the same manner as

bearings, as N. 20° W., S. 30° W., etc., in which case the limit of value is 90°.

The magnetic meridian should also be laid down. The angle of the true with the magnetic meridian is the variation of the compass.

The second division of the subject of military surveying has for its object the obtaining of the data necessary for the graphical representation of the relief of the ground, and the various forms which elevations and depressions present in nature; and, secondly, to give such a representation of these forms on a map, by conventional means, as shall convey an accurate impression of the ground. This must be done on the horizontal plane upon which the points determined by triangulation have been plotted, so that we are debarred from the construction of profiles or of perspective views. If the latter modes of representation are used, it is for the purpose of presenting forcibly to the eye the forms and contours; but they are no part of the subject of representation on a horizontal plane.

The plan adopted is to conceive the ground to be intersected by equidistant horizontal planes, cutting from its surface curves. The horizontal projections of the curves are represented on the sheet, and the inclination is inferred from their relative proximity, while the form is inferred from the shape and inflexions of the projections. It is evident, since the curves are horizontal, their projections on the horizon by vertical lines are curves, equal and similar in every respect.

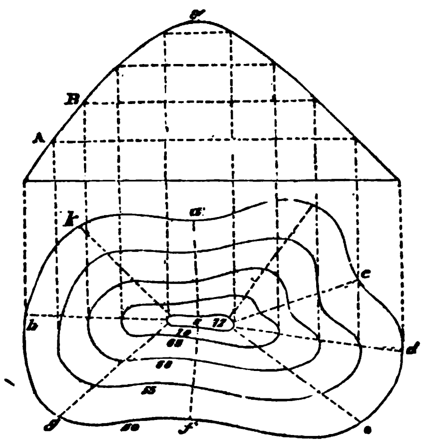


Fig. 7.

As the inclination becomes greater or less, it will be manifested by the crowding or separation of the curves in projection; and if the inclination is uniform, from the summit to the base, the projections will be equidistant along any common normal. This would be the case with a right conical or spherical surface.

Fig. 7 represents a vertical and horizontal projection of a hill, with the horizontal curves constructed. The numbers on the horizontal curves represent their elevations above some assumed plane of reference. The profile through *f* gives a steeper inclination than through *d*, since the curves are nearer than in the latter case.

If we pass these cutting places so near together that we may regard the shortest line drawn on the surface of the ground from one curve to its adjacent one as

a right line, as is sensibly the case in the vertical projection, Fig. 7, we are able to calculate the height of any point between the curves, above the common plane of reference, when we know the position of the curves, and the inclination of the slope.

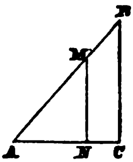


Fig. 8.

Let A B represent the line cut out of the surface of the ground, between the curves 55 and 60, by the vertical plane, the section made by which is represented in Fig. 7, and let it be required to find the height of any point, as the one marked M, above the plane of reference. A C in figure is the horizontal projection of A B, and N of the point M, and M N is the altitude of M above A. M N=A N tang. A; this added to 55 gives for the altitude of M, 55+N A tang. A. A N may be measured by a chain kept horizontal, and A obtained by methods to be described.

Then, if we can construct the projections of the curves, it is possible to find the altitude of any point of the ground.

Let Fig. 9 represent a vertical section of an eleva-

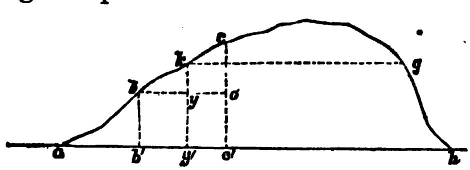


Fig. 9.

tion, the plane of the base being the plane of reference, and it is required to find points of horizontal curves

20 feet apart. It will be seen hereafter how the altitudes of the points b c d, where there is a change of inclination, are obtained. We now suppose them known, and that b is 27 feet and c 48 feet above the plane a h, and let it be required to find a point of the curve 40. It will be between b and c, and its projection will fall between b' and c'. It is 13 feet above b and 8 feet below c; assuming a point for the required one, and drawing through it a vertical line $k\,y$, and through b the horizontal line $b\,o$, we have two similar triangles, $b\,c\,o$ and $b\,k\,y$, and we have $o\,c : b\,c :: k\,y : b\,k$; whence $b\,k = \frac{b\,c \times k\,y}{o\,c} = \frac{13 \times b\,c}{21.}$; and again, $o\,c : k\,y :: b\,o : b\,y$; whence $b'\,y' = b\,y = \frac{k\,y \times b\,o}{o\,c} = \frac{13 \times b\,o}{21.}$, from which equations we find both the vertical and horizontal projections of the required point.

If we multiply the cutting planes indefinitely, we may obtain as many points as we choose, the projections of which, being joined, give the projection of curve (40); or, if it be desirable, the curve itself may be laid out on the ground, and other curves may be constructed in the same manner.

This method, however, is tedious, and is only resorted to for maps drawn on a large scale for fortifications or civil constructions.

In topography the scales are usually small and surveys quickly made, and hence it is usual to determine, with all the accuracy possible, the elevations of a

number of points, particularly chosen in respect to their relations to the form of the ground. The inclinations of slopes are also measured from time to time. Connecting the points of the same elevation we have a horizontal section, and between two points of known elevation, we may interpolate the proper number of horizontal curves. Hence it is very important to be able to judge accurately of the least sensible undulations.

In order to comprehend the slopes, the officer selects different high points from which he can observe them under different aspects; he marks with care the beginning, end, and changes of the slope; this enables him to recognize the parts where the inclination is uniform and those where it increases or diminishes. He also establishes, with the utmost care, the *divides* and the *lines of reunion* of the waters.

Standing on the *top* of the elevation, at a certain point, and looking down, the divide is the line of least slope, so that the rain separates along it, to flow to the right and to the left. Hence it is the longest normal between two consecutive horizontal curves. An instrument for measuring slopes, placed on the ground at the proper point, serves, when turned into different positions, to indicate it by its property of least inclination. Standing at the proper point, at the *foot* of the slope, and looking up, on the contrary, it is, of all lines of the ground passing through this point, the steepest. It may not lie, throughout its length, in the

same vertical plane; then, by walking along it and measuring it, and noting its change of direction, etc., we are able to lay it down on the map. Since it is the longest of the normals between two horizontal curves, it follows that the salient points of the curves are found upon it, which is also true of the *lines of reunion* of the water.

The latter lines, however, are generally much more easily recognized, since they are often indicated by water-courses, or by ditches, as it were, where the water from the two slopes unites. These lines are lines of the greatest slope if we look down from the top; looking up from the foot, on the contrary, they are the lines of least slope, of all through the same point.

If the inclination is uniform the normals are of equal lengths, and there is no divide. This is the case in the right conical and spherical surfaces, the horizontal sections being concentric circles. In Fig. 10, *a b* is the projection of the lines of divide, or water-shed; and in Fig. 11, A B is the projection of the line of descent of the water.

The properties of these lines prove their importance in giving the forms of the horizontal curves.

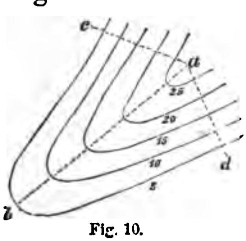


Fig. 10.

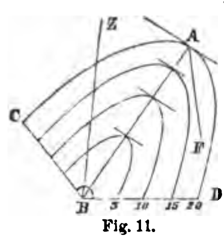


Fig. 11.

Having, by the level, determined the height of one of the principal points above an arbitrarily assumed plane, or, what is equivalent, having arbitrarily assigned an elevation to the point, supposed to be visible to a considerable distance on every side, let us suppose it to be occupied as a station, with a theodolite, or any of the less valuable instruments to be mentioned for measuring vertical angles, and the angles of elevation or depression of the remaining principal points to be determined. Their distances apart, in projection already calculated, multiplied by the tangent of the angle of elevations, respectively corrected for the height of the instrument above the station, is the difference of elevations, which, applied to the elevation of the station, gives the elevations of the other points above the arbitrary plane of reference. If one or more of the points be below the occupied station, the product of the tangent of the angle of depression and the horizontal interval is the difference of level between the instrument and the points. Thus we determine the elevations of the primary points. The elevations of the important secondary points may be fixed in the same way, either from themselves as stations, or by occupying only the primary points. Both processes usually coexist. The important points are the summits, the origin and end of the slopes, the places where they change, prominent points of the divides, ravine, and water-courses; these, with frequent measure of the slopes when they are uniform and

when they change, afford sufficient data to construct the curves.

These, when accurately projected, with the altitude of one, and the equidistance, enable one to ascertain the altitude of any point, and constitute an exact representation of relief. It is not the only method, however.

As a subsidiary method, in order to give more effect to the representation, and to enable the eye to judge more quickly of the relief, the lines of greatest slope are introduced. These lines are normal to the curves, and their projections are perpendicular to the projection of the curves. This supposes the curves to be so near together that the portion of the line of greatest slope between them is a right line. The next element of the line possesses the same property, without necessarily being a prolongation of the first, and so for each element; so that the whole line, regarded as continuous, is generally a curve of double curvature. It will be a plane curve, and its projection a right line, when the curves are parallel; and this is true when the ground assumes the form of a solid of revolution, such as a right cone or hemisphere, which, however, is not the case in nature.

Instead of making the projections of these lines, which are called *hachures*, continuous, it is usual to terminate them on the horizontal curves, which then will be sufficiently designated, and need not be traced in ink, provided the *hachures* below are not made in prolongation of the first drawn.

The length of the *hachures* depends upon the equidistance of the cutting planes.

The tint is graduated to represent different slopes, and supposes the ground to be illuminated from the zenith. If we conceive four vertical planes at right angles to each other, the parallel ones being one foot from each other, we have a parallelopipedon, the area of the cross section of which is one square foot; the area of an oblique section is greater, and is equal to one square foot divided by the cosine of the inclination of the cutting plane to the horizon. Then, for the same amount of light, it is evident that the smaller area will be more illuminated, for the light is distributed over a less surface. The depth of the tint thus would vary with the cosine of the inclination to the horizon, being white for horizontal surfaces.

This rule is not always adhered to, and in some services arbitrary scales of tints for slopes have been adopted, and all that is necessary is that the scale should be understood. In all, however, the tint deepens in the same ratio with the steepness of the slope, and is effected by making the *hachures* heavier and closer together.

The following general directions are important:

Commence with the feeble slopes, in order to increase the intensity of the tint more regularly.

When the projections of the horizontal sections are parallel, the *hachures* are right lines normal to both curves. When the curves are not parallel in projec-

tion, the *hachures* are curved, their extremities being respectively normal to the curves, at which they should accurately terminate.

The *hachures* of one section should not be continuous with those of the one above, but should lie about in the previous intervals. This enables the horizontal curves to be recognized, even when not traced in ink. They should have uniform thickness throughout their length, except when they correspond to the top or bottom of a declivity, when they are thinned off, to assimilate the appearance to the actual case in nature, where the slopes begin and end in a gradual manner.

When a slope suddenly becomes abrupt, the tint should be deepened by increasing the width of the *hachure* near the extremity, where the inclination is increased, or by interpolating short lines between the original *hachures.*

An artificial embankment, like those on roads, is represented by *hachures* drawn in the direction of the slope, and terminating in a point towards the base.

Natural precipices are irregular, and are represented by heavy lines drawn in the direction of the slope, and arranged so as to represent their form. The French rule is to make the interval between two parallel *hachures* equal to one-fourth the length.

The *hachures* are shorter for steep slopes, and are lengthened where the inclination to the horizon is less.

CHAPTER II.

As it is impossible to embody in a map all desirable items of information, it becomes necessary to accompany it with a written description or statement, usually called a "Memoir," which often, in addition to facts, contains a discussion of the relative advantages of certain positions, or certain routes or directions, in reference to a proposed project. It will then contain details of topography and also of statistics.

An acquaintance with the principles of the art of war, and experience in the field, generally indicate to the mind the points to be considered; but as all do not possess these advantages, it may be of use to allude to the items which demand particular attention. Some of the most important are here mentioned.

Rivers.—Their number, position, depth, width, sources, mouth, bottom, whether of sand, pebbles, rocks, or mud; whether there are quicksands or not. Is the valley narrow or broad? *Banks.*—Whether high and difficult of access; whether they afford military positions; whether there are islands; their positions; the degree to which they facilitate crossing. *Fords.*—Where situated; character; their existence often indicated by rapidity of current, recollecting that the maximum depth practicable for cavalry is about five feet; for infantry, three and a half feet to

two feet, depending on the current; for wagons, about two and a half feet. Does the river rise and fall rapidly? data as to degree. Is it navigable? if so, for what kind of boats, and between what limits? Are there any *bridges?* length, structure, width. Can they be easily destroyed or defended? *Points* favorable for forcing a passage; the width, depth, and velocity at these points. Means of crossing; number and dimensions of boats that can be collected for crossing at a given point.

Canals.—Width, depth, points connected, means of destroying them, etc.

Marshes and Ponds.—How are they formed? from springs, rivulets, or by overflow? Are they ever practicable? if so, when? Roads across them, width, description, etc. Are they unhealthy? Can the roads be easily repaired, destroyed, or defended?

Inundations.—How produced, and to what extent; time necessary, means of preventing them; between what points communication may be cut off; the detour they compel, etc.

Woods, Forests.—Position, shape, extent in all directions; character, whether open or tangled; practicable for horsemen, wagons, or infantry; large or small trees; species of trees; roads through them; character and position; character of the ground; are there any ridges, ravines, streams? what direction have they, and how long? can it be defended easily? the points where the roads and streams debouch.

Heath, Hedges.—Kind, height, thickness, good defence, or not. High heath generally practicable, where it is low is often marshy.

Roads.—Of every description, from the broad macadamized highway, to the merest trail to be noted; direction, width in feet; whether variable or constant; whether bordered with trees, hedges, or ditches; grade favorable for wagons with heavy loads or not; state of repair, facilities of repair; whether always practicable, and when; whether commanded within cannon range; whether other roads can be opened easily; means of obstructing them; number of hours' march between positions for camps; sandy or hard; road covering, positions for defence; defiles, their length, width, nature of ground at their debouches.

Fortifications, permanent or temporary.—Their character, objects, defensive relations between them, etc.

Fortified Cities.—Population; temper of inhabitants; supply of provisions; means of obtaining them; whether suitable points for dépôts, workshops, and hospitals, or not; particular description of fortifications, etc.

Villages.—Kind of houses, wood, brick, or stone, in contact or separated; gardens with hedges, or not; means of attack and capacity for defence; walls, etc.

Military Positions are to be considered under the following points of view: the actual extent, variety, and contour of the ground; the facility of communication between different parts; adaptation to the principal arms of service; command over surrounding

ground; its approaches and debouches; whether difficult for the enemy, with accurate descriptions of the natural or artificial obstacles to his advance. The facilities for retreat; whether the roads are commanded or not by surrounding ground; if so, at what distance; the character of the flanks.

Statistics.—Kind and fertility of soil, productions; how much wheat and corn to the acre; amount of forage; horses, number and quality; beeves, calves, sheep, pigs; grist and saw mills, and their capacity; manufactures. Wagons, boats, mules, healthiness of climate, supply of water. Number and capacity of houses in villages; number and temper of inhabitants.

The memoir should be clear and concise in style, and legibly written, leaving a margin on each sheet for remarks of the chief of staff, or commanding general. It should commence with the order under which the reconnoissance was made, and should briefly state all the steps pursued, in the order of their occurrence.

Particular care should be taken in the orthography of proper names, and, to insure accuracy, it is well to obtain them of educated inhabitants of the country.

Nothing should be reported as true, unless it has come within the knowledge of the officer; but it does not follow that information obtained from people of the country, or other sources, is to be neglected; on the contrary, when not manifestly untrue, it should be

reported with the attendant circumstances, to show what degree of credence is to be given to it.

When the reconnoissance has been ordered in reference to a projected operation, the officer, after a detailed description of such points as bear upon its success, proceeds to a discussion of the means to be employed, the advantages to be reaped, and the dangers to which it is exposed by virtue of the probable movements of the enemy, etc., which it is apparent opens up a vast field of hypotheses, which, however, a methodical mind, familiar with the details of war, and the habits of the enemy, will speedily reduce to a very few.

A proper treatment of this portion of the subject requires study; and as the operation may be an attack or defence of a village, a position for offensive manœuvres with the whole army, or for a defensive battle, the passage of a river, the assault of an intrenched camp, posting of advanced guards, either an operation of *petite guerre*, or of the most vital importance, it is evident that mental abilities of a high order and acquaintance with all the branches of the art of war may be necessary for its perfect elucidation.

Mountains and Hills.—Do they form a chain? its direction; or are they isolated? Nature of the slopes; are they gentle or abrupt, open or covered, cultivated or not, rocky or smooth? Are they practicable for either arm of the service? if so, for which ones, and at what points?

A slope of 7 upon 4 (7 altitude, 4 base) is about 60°, and is impracticable for infantry; one of 1 upon 1 is difficult for infantry. One of 4 upon 7 (about 30°) is impracticable for cavalry. One upon 12 (or about 5°) is easy for wagons.

It is necessary also to give the time necessary to ascend them. Is the summit a plateau or not? Describe the ravines; are there any springs? what facilities for obtaining water?

The projection which we make of the ground on the map is a figure smaller than, but similar to, that obtained by projecting the points on a plane tangent to the sphere, which we have assumed the earth to be, by means of radii of the earth.

If we call any distance on the map unity, the fraction which we obtain by dividing this length by the distance between the projections of the same points on the tangent plane, is called the scale of the map. If the projected distance between two points be 5,000 times greater than its representative on the map, the scale is said to be $\frac{1}{5000}$, and the area of the map is $\frac{1}{5000}$. part of that which it represents.

The decimal nomenclature for scales is usually but not universally adopted. They are sometimes described as one, two, or more inches to the mile. One mile containing 63,360 inches, a scale of one inch to the mile would be in the decimal system $\frac{1}{63360}$

The term *scale* has been extended in its signification to denote the geometric figures which

Fig. 12.

make known the distances on the ground by means of their representatives on the map, or reciprocally. When the map is completed, a scale of the form in Fig. 12 is often placed upon it, which enables one to take off distances with tolerable accuracy; but, for the construction of the map, a better form, called the diagonal, is represented in Fig. 13. To construct it, let *a b* represent the unit of the scale, which may be one inch, half inch, or any other length. On *a b* describe a square; divide *a b* and *d c* each into ten equal parts; draw *a f* and the other nine parallels; produce *b a*, and lay off the unit of the scale as many times as may be necessary. Divide *a d* into ten equal parts, and draw the parallels to *a b* straight through the points of division.

The triangle *a d f*, the base *a f*, is one-tenth of the unit of the scale, and there are nine other similar triangles, the bases of which are nine-tenths, eight-tenths, etc., of the distance *d f*. The base of the smallest triangle is one-tenth of *d f*, or $\frac{1}{100}$ of the unit of the scale.

Then, to take off in dividers the unit of the scale and any number of tenths, place one foot at 1, and extend the other to the point between *a* and *b*, marked by the figure designating the tenths. To take off the unit of the scale increased by any number of tenths and hundredths, place one foot of the dividers on the

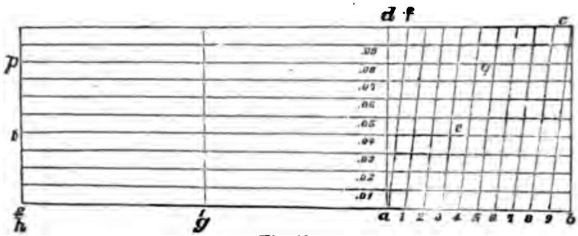


Fig. 13.

perpendicular through 1, where it intersects the parallel which denotes the hundredths; then extend the dividers to that line between *a d* and *b c* which designates the tenths. Thus *p q* represents 2.58.

The unit of the scale may be the representative of a mile, or ten miles, or any arbitrary distance. If, for instance, it were 1000 feet, then each of the equal parts, *a* 1 2, represents 100 feet, and the distance between *a d* and *a f*, measured on the first parallel, is 10 feet, on the next 20 feet, and so on, so that *l e* would represent 2340 feet.

The scale employed depends upon the character of the map, and hence varies greatly.

A scale of $\frac{1}{2400}$, or one inch to 200 feet, permits the representation of small details. For a small extent of country, a scale of about six inches to a mile is sometimes used. For greater extents of country, three inches to a mile, or $\frac{1}{21120}$, which is a large scale.

For laying off angles we use a protractor, which is either semicircular or rectangular. When semicircular, the circumference is divided into 360 equal parts,

and numbered each way from the extremity of the diameter, from zero to 180°, and from 180° to zero, each equal part representing a half degree. To lay off from a point a line, making with a given line any angle, place the centre of the protractor over the point, so that the diameter coincides with the given line, and with a fine-pointed pencil mark the point on the circumference numbered with the figure designating the number of degrees; join this point with the given point for the line required. The use of the rectangular protractor is similar.

Angles may be laid off by a scale of chords, which is constructed as follows. Let C D be a quarter of a circumference. Fig. 14. Conceive it divided into 90° equal parts, and each of them joined with C. These lines are the chords for every degree from 0 to 90°. Take off these lengths, and embody them in a scale: this is a scale of chords. It is usually found in a case of drawing instruments. The chord of 60° is always the radius of the circumference from which they were taken.

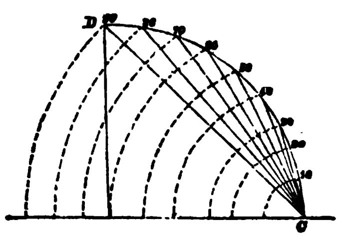


Fig. 14.

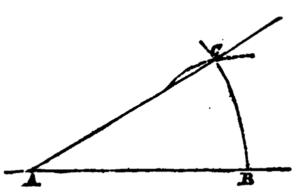


Fig. 15.

To lay off an angle from any point, let A B be the given line, and A the

point. Take from the scale the chord of 60°, and, with A as a centre and this as a radius, draw the arc B C. Then take from the scale the chord of the given angle, and, with this as a radius and B as a centre, describe an arc intersecting B C in C; join A and C, then B A C is the given angle.

For drawing right lines a straight-edge ruler is re-

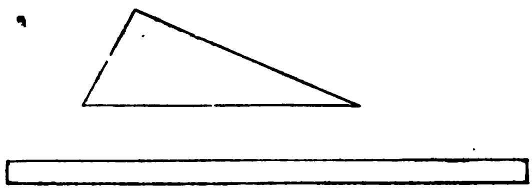


Fig. 16.

quired. A right-angled triangle, one side being considerably longer than the other, is very useful in connection with the ruler. Placing its hypothenuse along the edge of the ruler, and sliding the triangle along the ruler, each side remains parallel to itself in all its positions; so we may draw parallel lines. The other side, in all its positions, being perpendicular to the first, we can draw a perpendicular to a given line through a given point.

A pair of dividers, rule and triangle, and protractor are sufficient for field purposes. It is, of course, convenient to have other instruments in all cases.

To copy a map on the same scale, divide it up into squares, by pencil lines lightly drawn. On the sheet to be filled, construct the same number of squares of

the same dimension, and make each a copy of the corresponding one on the map. This may be done either by the eye, or by constructing the co-ordinates of as many points as may be necessary. The direction of a right line is known when two of its points are determined, which may be done by noting where the line or its prolongation crosses the sides of any of the squares. Where there are many details to be put in, it may be necessary to multiply the number of squares, or to divide them into triangles by drawing the diagonals.

A piece of tracing paper or muslin, stretched over a map, permits the lines to be seen through it, and they may be traced by a pen.

If the copy is enlarged or contracted, the sides of the new squares bear to those on the map the ratio of the two scales. A scale of reduction is formed, Fig. 17, by drawing two lines oblique to each other, of such lengths that $\frac{A\ B}{B \cdot C}$ is equal to the ratio of the two scales.

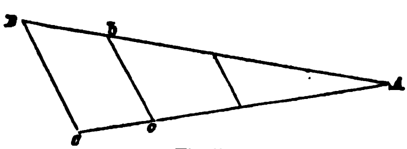


Fig. 17.

Join A and C, and draw the other lines of the figure parallel to B C, then it is evident that *b c* is the reduction of the line A *b*. There are instruments suitable for a transfer of a drawing on a different scale, which it is scarcely necessary to describe.

CHAPTER III.

MEASUREMENT OF ANGLES.

For this purpose the best instrument is the theodolite. It can be firmly mounted, admits of thorough adjustment, and gives angles generally to within a few seconds. Ordinarily, however, circumstances compel the use of instruments of less precision, among which are the sextant, plane table, and Schmalcalder or prismatic compass. The latter, indeed, is one of the most useful of all devices, as with it alone it is practicable to make all the observations necessary to construct the horizontal projections of any number of points. It is well, however, to understand what degree of accuracy we are to expect from a compass.

The angle between a vertical plane through the axis of the needle, and the meridian, is the *declination* or *variation* of the compass. The *mean daily value* of the declination may be regarded as a constant quantity during the operations of a campaign, and is west for all points in the United States east of the line of *no declination*, which, in 1850, passed through Lake Erie, and followed a south-easterly course, entering the Atlantic Ocean near Wilmington, N. C. It

has a slow motion to the west. The *declination*, at points west of this line, is east, and in general terms may be said to increase as we recede from this line. Hence, the mean daily variations, determined at intervals of several years, will be found to present generally a decided difference.

The fluctuations in the declination at the same place, during 24 hours, deserve notice, as they are sufficient to produce considerable errors, attaining a value as great as 20′. These fluctuations vary with the seasons, and are said to be greater in the summer than in the winter, and to vary chiefly in the daytime, the declination being nearly constant during the night.

Again: the compass bearing, particularly in the small prismatic compass, cannot be read with certainty nearer than 15′; and when, as it may well be, the errors of declination and reading both have the same sign, the total error may be as much as half a degree, and even more. This, however, does not render the instrument valueless, although it would prevent its use in fixing the principal points of an accurate survey. The needle is mounted so as to remain horizontal, when not disturbed, upon a fine-pointed pivot, working in a smooth, hard socket, of quartz generally, to reduce to a minimum all impediments to its free oscillations.

To magnetize a needle, it is placed, its longest dimension north and south, and two magnets are placed

on the needle near its middle point, the south pole of one on the side of the north pole of the needle, the north pole of the other towards the other end; then pressing firmly in, and giving the magnets equal inclinations to the needle, they are drawn each to the end of the needle to which it corresponds. When they reach the ends they are disconnected from the needle and replaced in the first positions, and the process is repeated as often as may be necessary.

To judge of the degree of magnetizing, and to ascertain whether the maximum has been reached, the needle is made to raise different weights, not forgetting to reapply the magnet afterwards, since every effort of this kind exhausts some portion of the magnetic virtue.

The prismatic or Schmalcalder compass may be held in the hand; but it is both more convenient and more accurate to have it mounted on a tripod, or a single staff, particularly when it is desirable to take a number of observations at the same station. With the staff they can be taken and recorded by the same person, without loss of time, without a new adjustment, which would be necessary for each observation, as the officer would be obliged to lay it down in order to record the bearing just taken.

The Fig. 18 represents the prismatic compass. A is the box and B the card to which the needle is attached, and *a* the pivot which supports both needle and card. E is a sight-vane, having a thread to direct the

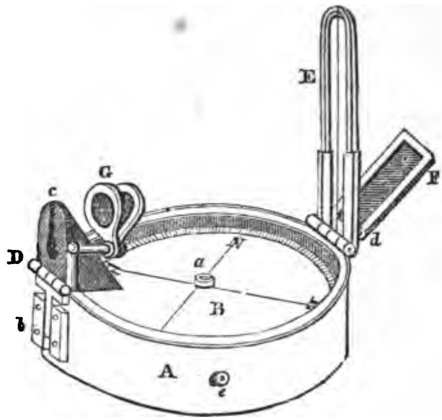


Fig. 18.

line of sight; and F is a reflector, to enable observations to be made upon bodies above the horizon. E and F turn about hinges, so that they can be folded upon the plate; and at D is seen a hinge about which the lens turns. The card is differently graduated in different instruments, sometimes from zero to 360°, in others to 180° and back to zero; and again in others there are four quadrants, each from zero to 90°. The curved face of the prismatic lens is turned towards the figures just below it on the card. The light coming from them is first refracted at the curved face, then received upon the inclined plane face, and reflected to the eye horizontally. The eye then being applied at *c*, when the needle comes to rest, looking horizontally, sees the hair E, and apparently coincident with it a division on the scale.

At G are colored glasses, which turn about a joint, and which are used when a bearing of the sun is taken. At *e* is a spring, which, being pressed by the finger at the time of observation, and then released, checks the vibrations of the needle. On the other side of the box is a lever, by which the needle is thrown off the pivot, and this should always be done when the instrument is not in use, for the constant playing of the needle wears the point upon which it is balanced. The value of the instrument depends greatly upon the fineness of the point of support.

The graduation is in some to half degrees, and others to 15′, depending upon the length of the needle, or the diameter of the card. They are made of different sizes, from two and three inches to six in diameter. The instrument has a brass cover. For use, it is usually carried in a leather case, made to fit it, swung over the shoulder by straps, or without straps it is carried in the pocket or satchel.

To use the instrument, adjust the prism by moving it up or down by its slide, so that the divisions and figures on the card are seen distinctly; apply the eye to the aperture in rear of the prism, and bisect with the thread the object whose bearing is to be taken; press the spring *e*, to check the vibrations of the card, and read the degrees and parts corresponding to the division on the scale which coincides with the thread. By moving the eye up and down, one is able to see the thread and division at the same time.

This is a very valuable instrument for military purposes. It gives magnetic bearings to within a quarter to a half degree, depending upon the diameter of the card. It is portable, requires no adjustment, and is sufficient to enable us to determine any number of points. The angles measured by it are in the plane of the horizon. The card should be horizontal, or nearly so; if too much inclined it does not move freely.

A vernier is an auxiliary graduation, which enables us to estimate fractional portions of the smallest divisions of the limb. It applies equally to linear and angular measurements, and when explained in one case, it will readily be understood in the other.

For sake of illustration we will take the case of the sextant; but first we will give a general explanation. Let us take two equal arcs, one on the arc of the index arm, and one on the limb, supposing the former to be subdivided into n equal parts, each of which is equal to d, the latter to contain $(n-1)$ subdivisions equal to D. Hence we will have $(n-1)\,\mathrm{D}=n\,d$, from which results:

$$\mathrm{D}-d=\frac{\mathrm{D}}{n}$$

$$2\,(\mathrm{D}-d)=2\frac{\mathrm{D}}{n}$$

$$m\,(\mathrm{D}-d)=m\frac{\mathrm{D}}{n}$$

The graduations of the two arcs being in the same di-

rection, if the zero of the vernier is found between two graduations of the limb, the distance which separates it from the first of the graduations will be $\frac{D}{n}$ if the first division of the vernier coincides with a division on the limb, $2\frac{D}{n}$ if the second division of the vernier coincides with a division on the limb, $m\frac{D}{n}$ if the mth division of the vernier coincides with a division on the scale. Hence, in reading an angle we look along the vernier, to see the number of the division which coincides with a division on the limb, and multiply this number by $\frac{D}{n}$, and add the product to the number of degrees and parts of a degree corresponding to the division on the limb which the zero of the vernier has just passed.

It may happen that no division of the vernier coincides with a division on the limb, but that one of the equal parts of the latter contains two divisions of the former. If we suppose the middle of the space on the limb to coincide with the middle of the space on the vernier, the error will be $\frac{D}{2n}$, since $\frac{D-d}{2}=\frac{D}{2n}$.

Hence we may say that while the vernier reads to $\frac{D}{n}$, the approximation is to $\frac{D}{2n}$.

In the pocket sextant, $\frac{D}{}$ is the smallest space on the

limb, 30′. An angular space of 14° 30′ on the vernier is divided into thirty equal parts. Hence n being equal to 30, $\frac{D}{n}$ is equal to 1′. So if the zero of the vernier should fall between the two divisions which correspond to 87° and 87° 30′, we look along the vernier and find the 17th division, coincident with a division on the scale, the angle measured will be 87° 17′.

On the arc of excess of the sextant, when the zero falls between two divisions, since the graduations are in different directions on the two arcs, the reading is taken as follows: Read the degrees and parts of degree corresponding to the last division passed by the zero; run the eye back on the vernier till coincidence is discovered, as before supposed, at division 20 of vernier, then D—20′=10′ is to be added to reading on limb. Generally, then, look back on the limb till coincidence is found; estimate the minutes and seconds corresponding and subtract them from D; add the remainder to reading on limb.

It is needless to say that, if the zero of the vernier coincides with any division on the limbs, the angle will be given by the number of degrees and parts of degree corresponding to this division.

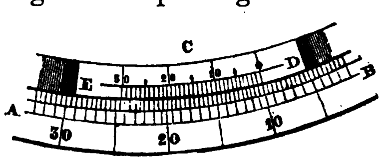


Fig. 19.

E D, fig. 19, represents the vernier above described; the smallest division on the scale is 30′, and

thirty divisions of the vernier cover twenty-nine on the limb. The least count of the vernier is always equal to the least graduation on the limb divided by the number of parts on the vernier, in this case 30′ divided by 30, or one minute. The reading on the limb is evidently 10°.

Theodolite.

This instrument is most valuable, since it measures horizontal and vertical angles with great accuracy, and is suitable also for making astronomical observations for latitude and time of day.

At A and B are seen two circular plates constituting the horizontal limb, the upper one carrying the verniers, the lower having a larger diameter than the upper, and a chamfered silvered edge to receive the graduations, the number of which depends on the circumference of the limb. Where it is five inches in diameter the graduations are usually to half degrees, the vernier giving readings to one minute. A microscope, E, serves to read the verniers, of which there are two, at opposite extremities of a diameter, one of which is at *a*.

The axis C is of conical shape, and is composed of two concentric surfaces nicely fitted to each other and working easily. The external one supports the plate B, and the inner is attached to A, which bears the superstructure. The external part of the axis fits into

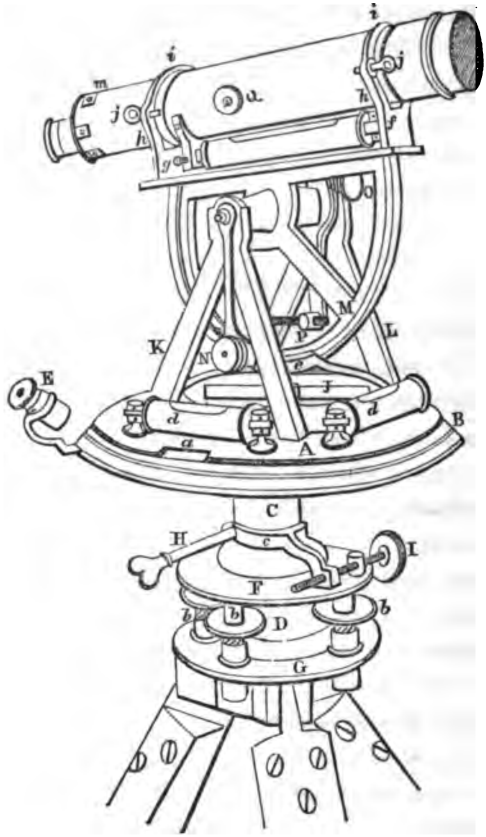


Fig. 20.

a ball, D, and the parts are held together by a screw at the lower end of the internal axis.

The parallel plates F and G are held together by a ball and socket at D, and are made parallel by four

milled-headed screws, three of which are shown at *b* in the figure. These turn in hollow cylinders inserted in the plate G, and their heads press against the plate F. Beneath there is a female screw, adapted to a staff head, which is connected by brass joints to the tripod. The legs of the latter, when they are brought together, make a conical figure, and when extended constitute a firm support.

The limb B can be fixed in any position by the clamp screw H, which closes the ring C upon the axis. The tangent screw I permits a slight motion of the plate B when H is clamped.

A similar pair of screws, clamp, and tangent perform the same office for the vernier plates. These are not shown in the figure.

On the vernier plate are two spirit-levels, at right angles to each other, to level the limb B. At J is a compass.

The frames K and L support the cylindrical pivots of the axis of the vertical arc. This arc is graduated, and has a vernier *e*, which serves to read to one minute, and the microscope N enables one to read the vernier in any of its positions.

O is the clamp screw and P the tangent screw for the vertical arc. The level under the telescope is attached to the tube at one end by a joint, and at the other by a capstan-headed screw *b*, which, being turned, moves the end oft he level up or down; and at *g* is a screw which moves the other end of the level horizon-

tally, so as to put its axis in the vertical plane, through the line of collimation of the telescope.

The telescope rests in cylindrical rings which are supported by the Y's *h h*; it is held in its place by the clips *i i*, which are opened by removing the pins *j*.

At *m* there is a reticle of two spiders' lines at right angles to each other. The adjusting screws for the wires are four in number and work by pairs. One should always be loosened before the opposite one is tightened.

The telescope is of the ordinary achromatic form. The tube of the object-glass is moved to and fro by the screw-head Q. The tube containing the eye-glass may be extended or pushed in, in order to adjust to distinct vision. By a motion of the object-glass the image is thrown on the plane of the reticle. The eye-glass should be placed to show the cross-hairs and the image distinctly. The image is in the plane of the wires when a motion of the eye in any direction fails to separate the wires and image.

The first adjustment is to make the line of collimation coincide with the axis of the rings in which the telescope rests. To make it, direct the intersection of the cross-hairs to a distant well-defined object, causing the horizontal wire to cover a well-marked point of the object. Turning the telescope half round about its axis, so as to bring the level on top, if the point remains on the wire the adjustment is complete; if it does not, move the wire over one-half the

deviation by the screws at *m*, releasing one before tightening the other, and correct the other half by elevating or depressing the telescope. Renew the operation, to see whether half the deviation has been correctly estimated; if not, another approximation must be made. A similar course of procedure adjusts the vertical wire, and the observed point will be found to remain in apparent coincidence with the intersection of the cross-hairs during a rotation of the telescope.

The second adjustment has for its object to make the axis of the level parallel to the line of collimation. Open the clips *i i*, clamp the vertical limb, and bring the bubble to the middle of the tube by turning the screw P. Take the telescope off its supports and reverse it, end for end, with care. If in this new position the bubble is in the middle of the tube the adjustment is correct; but if it retires to either end, bring it to the middle, half by the screw *f*, which gives a vertical motion to one end of the level, and half by the tangent screw P. This is repeated till the adjustment is thorough. Revolve the telescope in the Y's; if the bubble does not remain in the middle, turn the screw *g* until it is brought back. Re-examine the first part of the adjustment. The screw *g* gives a lateral motion to the level.

The third adjustment requires the axes of the levels on the limb to be perpendicular to the axis of the instrument. For this purpose clamp the screw H, and

turn the vernier plate till the telescope is over two of the parallel levelling screws. By turning the latter in appropriate directions, bring the bubble under the telescope to the middle of its tube. Turn the vernier plate 180°; if the bubble remain in the middle, one line of the horizontal limb is horizontal; if not, bring the bubble back, half by the levelling screws and half by the screw P, and repeat this till the bubble remains in the middle in either of the positions. Turn the vernier plate 90°, to bring it over the other two parallel plate screws, and go through the same process for these. If these operations have been correctly performed, the bubble will remain in the middle while the vernier plate revolves. The axis of the limbs is now vertical. By means of the adjusting screws of the levels and the vernier plates, bring their bubbles to the middle of their respective tubes.

These adjustments being performed, the vertical limb should read zero, but it generally does not. The vernier may be adjusted, but it is better to proceed as follows, viz.: To obtain the elevation or depression of a point, direct the intersection of the cross-hairs upon it, and read the vernier on the vertical limb and record. Reverse the telescope end for end, and turn the vernier plate 180°, and remeasure the vertical angle and record. The half sum of these readings is the angle, unaffected by a faulty position of the vernier.

The horizontal limb is provided with two verniers at opposite extremities of a diameter, and the gradua-

tions run from zero to 360°. On the vertical limb, the graduations proceed from zero to 45°, in either direction. The angle read from the vertical limb is then either the altitude or depression of the object observed. The complement of the altitude, in the first case, and 90° — the depression, in the second case, gives the zenith distance of the object.

To measure a horizontal angle with the theodolite, place the axis directly over the centre of the station, by means of the plumb-line suspended from the axis. Bring the telescope over each pair of levelling screws alternately, and by turning the individuals of each pair in opposite directions, make the limb horizontal, which will be the case when the small levels retain the bubbles in the middle, as the instrument turns. Clamp the horizontal limb and direct the telescope to one of the objects. Clamp the vernier plate, and by its tangent screw cause the object to appear on the intersection of the cross-hairs; read the verniers on the horizontal limb and take their mean. Unclamp the vernier plate and turn the telescope as before to the second object, and take the mean of the two vernier readings. The difference between the two means is the angle required.

The fact that the lower plate is movable enables us to repeat the measurement on a different part of the limb. To repeat the angle just measured, unclamp the lower plate, the upper being clamped to the latter. Turn the instrument till the telescope is again di-

rected to the first object; clamp the lower plate, and complete the pointing of the telescope by the tangent screw I. Unclamp the upper plate and turn it till the telescope is directed to the second object; clamp, apply the tangent screw, and read the verniers as before. The difference between this and the last mean is another value for the angle between the objects. It is well to repeat the angle four or five times, and take the value obtained by dividing the difference between the first and last readings by the number of repetitions, for the angle.

Sextant.

The optical principle involved in the sextant is, that a ray of light reflected once by each of two plane reflectors, in a plane normal to their intersection, is deviated from its original direction, by an angular amonnt equal to twice the angle of the reflectors. To prove this, let A C and C B represent sections of the reflectors by a plane perpendicular to their intersection, and R M an incident ray reflected at M and N, making, in each case, the angles of incidence and reflection equal. Then N O is its direction after two reflections, and the angle R O N is the deviation, which is equal to twice A C B. Draw normals to the reflectors at the points of incidence and denote by ϕ and ϕ' ϕ'', the angles of incidence marked in the figure. The angles D and D′ are evidently equal to A C B. But ϕ being an exterior angle of the triangle,

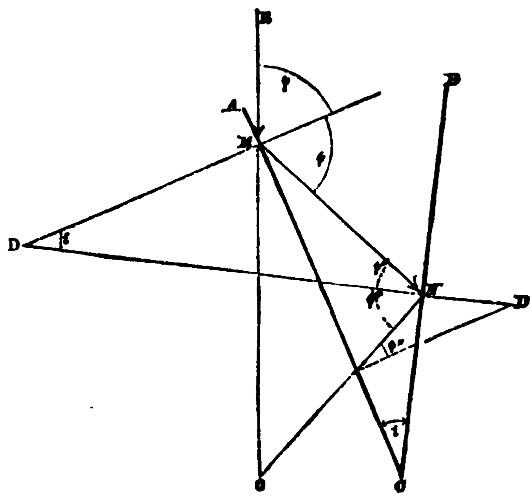


Fig. 21.

D M N is equal to $\phi'+i$, and from the triangle M′ N D′, ϕ' being an exterior angle, we have

$\phi'=\phi''+i$, and from the first $\phi'=\phi-i$.

Subtracting these equations, member by member, we have

$$\phi-\phi''=2\,i. \qquad (1)$$

But from the triangle M N O we have $2\,\phi=2\,\phi'+O$, or substituting for ϕ' its value,

$$2\,\phi=2\,\phi''+2\,i+O.$$

But from equation (1) $2\,\phi=2\,\phi''+4\,i$.

Hence $\quad O \quad =2\,i$.

If the reflector B C be transparent at N, the eye at O will see R and R′ apparently coinciding, since the light from both objects enters the eye from the

same direction, the first after two reflections, the second directly, and the angle at the eye between R and R′ is O, which has just been proved equal to 2 i. Hence, if we can provide any means of measuring the angle of the reflectors, when the objects are seen in coincidence, double it, and we have the angle between the objects.

A double-framed sextant is shown in the figure. F

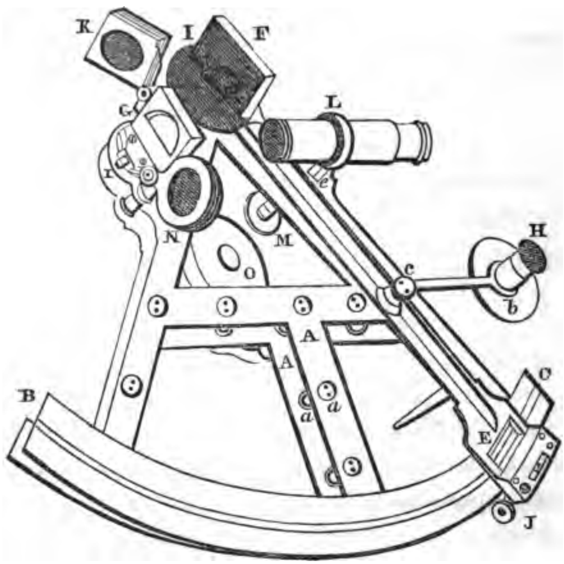


Fig. 22.

is one of the reflectors, G is the other, which, however, is only half silvered on the back, the half farthest from the plane of the limb being transparent. F is called the index glass, and rests on a circular plate, which is

movable by the index arm I E, which turns about the centre of the arc B C. The index glass obviously varies its inclination to the horizon glass G, as the index arm is made to take different positions. K and N are colored plane glasses to qualify the light from the sun. L is a telescope, and H a microscope to read the vernier E. At A the double frame is shown connected by braces, making the instrument firm. O is the handle. B C is graduated into angular divisions, and each half degree is marked as a whole degree, so that if the arc B E be considered as 55°, the graduation would read 110°. This spares the necessity of doubling the angles made by the reflectors.

The telescope is supported in a ring attached to a stem, *e*, called the up and down piece, which can be raised or lowered by turning the screw M. The object of this is to place the telescope so that it will receive equal portions of light through the transparent and from the silvered part of the horizon glass, thus making the two images appear equally bright. The planes of the index and horizon glasses are set perpendicularly to the plane of the limb, but are susceptible of slight changes of position by means of small adjusting screws, one of which is seen at *i*. In some instruments no provision is made for changing the position of the index glass. It is set by the maker at right angles to the limb.

The zero of the graduation should be at the point of intersection of the plane of the index glass with the

limb, when the former is parallel to the horizon glass. The graduation extending to a few divisions to the right of the zero, is called the "arc of excess." If the zero is not at the proper point, there is an index error. The index arm carries a vernier. The sextant is generally provided with two telescopes, one of which inverts.

The pocket sextant differs in arrangement from the larger variety, but not in principle. The index and

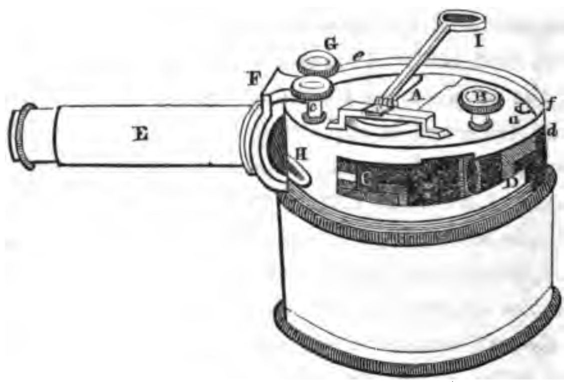


Fig. 28.

horizon glasses are enclosed in a brass box of two or three inches diameter. The top unscrews and is screwed on the bottom for a handle. The box protects the glasses from all ordinary chances of injury or displacement. The horizon glass may be moved slightly for adjustment, by taking the key c from its resting-place, and turning with it the levers *a* and *d*. The

screw G secures the telescope to the box; but the instrument may be used without the telescope. The eyepiece has a colored glass, and two in the interior of the box may be interposed, if necessary, to moderate the reflected intensity. The graduation is to 30′ on the scale, and read by the vernier to 1′, the graduation extends to about 140°. I is the movable microscope for reading the vernier. The index glass is fixed in place by the maker, and will remain in adjustment, unless under extraordinary treatment; hence no means of adjustment for it are provided.

This is the usual form of the pocket sextant, although, in some instruments, certain modifications have been introduced.

There are three adjustments for the sextant, as follows: 1. To make the index and horizon glasses perpendicular to the graduated limb. 2. To make these glasses parallel when the index is at the zero of the scale. 3. To place the optical axis of the telescope parallel to the graduated limb.

1st Adjustment.—Remove the telescope; bring the index to the middle of the scale; hold the instrument horizontally and look obliquely, so as to see one portion of the limb by direct vision, and another portion by reflection. If the appearance is continuous and not broken where the two portions seem to join, the index glass is perpendicular to the limb. This glass is rarely out of place, and, as before observed, generally no means of restoring it are provided.

The horizon glass is perpendicular to the limb, when a sweep of the index arm causes the reflected image to pass exactly over the direct. The screw *i* serves for correction, if any is necessary.

2d Adjustment.—This may be made, but it is rarely, if ever, done. To do it, set the index at zero, and turn the telescope to some small distant object; if it appear double, ease the screws which attach the horizon glass to the instrument, and turn it till the image becomes single, then tighten the screws, and re-examine the first adjustment. A more usual course is to ascertain the amount of error and apply it to the observations. If the zero of the vernier is to the right of its appropriate place, every angle will be too great, and if to the left, every reading will be too small. The amount of error is called the *index error*, and is the reading of the zero of the vernier when the glasses are parallel. It is easy to obtain its value. For this purpose place the index near the zero, and look at a star, or, in its absence, at a very small distant object. By moving the index arm to and fro, two images of the star are seen; clamp the index arm, and by means of the tangent screw make them coincide. The glasses are now parallel, and the reading of the limb is the index error. If the zero of the vernier is to the right of the zero of the limb, we are reading on the arc of excess, and the index error is positive, and is to be added to every observation; if on the main limb to the left of the zero, it is to be subtracted.

By the sun.—Set the zero of the vernier at about 30′ on the limb and clamp; direct the telescope to the sun, interposing one or more colored glasses; holding the limb vertical, two images of the sun will appear; by the tangent screw bring them into tangency at the highest point of one and lowest point of the other, and read the limb, record it as "on the arc." Unclamp and set the vernier on the other side of the vernier at about 30′, two images again appear. Bring about tangency as before, and record the reading off the arc. Take half the difference for index error.

EXAMPLE.

Reading on the arc,	31′	56″
" off the arc,	31	22
Difference,	0.	34″
Index error,	—	17″

The sum of the readings should be equal to twice the apparent diameter of the sun, as given in the Nautical Almanac, for the date of observation. If the reading "off the arc" had exceeded that on, the index error would have been additive.

3d Adjustment.—This is made by means of two parallel wires placed in the common focus of the telescope, to direct the eye to the middle of the field of view, in which all observations should be made. They divide it into three nearly equal parts. The sun and moon, when their angular distance apart is

90° or more, are made tangent at one of the wires, the position of the sextant is then altered to bring them on the other wire, and if the tangency continues the adjustment is complete; if not, the position of the telescope must be altered by two adjusting screws connected with the up and down piece.

The sextant measures angles in the plane of the objects and the eye, and hence it is necessary to put the graduated limb in this plane. When it is used for triangulation, the measured angles must be corrected for *reduction to the horizon*. When the plane of the instrument is but slightly inclined to the horizon, it may happen that the error of assuming the measured as the reduced angle falls within smaller limits than the errors of observation, and the correction may be dispensed with. This and many other corrections, of small value in surveying, are applied or not, according to the sound discretion of the officer, keeping in view the degree of accuracy which it is desirable to attain.

When the sextant is applied to measure an altitude, the graduated limb is held in a vertical plane. When the natural horizon is visible, as on extended plains or at sea, no collateral instrument is necessary, and the manner of observing is as follows: holding the instrument in the right hand, and in a vertical position, the observer directs the telescope to the horizon, exactly under the heavenly body, and with the left hand moves the index arm from the zero towards the lower

end of the limb, till an image of the body enters the field and is near the horizon; then he clamps the index arm, and turns the tangent screw till the image, if of a star, is seen on the horizon. If the sun is used, he makes its image tangent to the horizon, at either the highest or lowest point of the disk. The angle read from the limb corrected for index error, is the *apparent* altitude of one of the limbs of the sun, or of the star's centre. If, however, the observer is above the sea horizon, as, for instance, on the deck of a ship, this altitude must be diminished by a correction for dip of the horizon. The angle corrected for the sun's semidiameter, additive or subtractive, as the lower or upper limb was observed, becomes the apparent altitude of the centre. It is not the true altitude, however, as it would be seen from the centre of the earth, were there no atmosphere. The refraction of light by the atmosphere increases the apparent altitude, while parallax decreases it; hence a correction for refraction is to be subtracted, and one for parallax added.

The irregularity of the ground generally prevents the use of the natural horizon, and recourse is had to an artificial one, which consists usually of a flat vessel of mercury covered by a roof-shaped frame, its faces being of glass. A piece of glass, the back face covered with pitch, to prevent reflection from the second face, mounted on a tripod of screws, and provided with a small level to test its parallelism to the horizon, is another form.

The image of the heavenly body, seen by reflection from the artificial horizon, is as far below as the body is above the horizon, and, as the instrument measures the angular distance between these two objects, it follows that this is the double altitude. To measure a double altitude, hold the sextant as prescribed in the last case, directing the telescope to the reflected image, and with the left hand slide the index arm along the limb till a second image appears. When they either overlap slightly, or are slightly separated, clamp, and, by the tangent screw, make the disks tangent at their highest and lowest points. When they are approaching tangency, it may be well to clamp and await the instant of contact. The angle read from the scale corrected for index error is the apparent double altitude of the upper or lower limb of the sun: upper when the altitude is increasing, as in the morning, if after tangency the images overlap, and lower, if (altitude increasing) they separate after tangency. If the altitude is decreasing, and the upper limb is observed, the images separate after tangency; if the lower, they overlap.

The second image, brought into the field of view by a motion of the index arm, is formed by light from the sun, which is first incident on the index glass, then reflected to the horizon glass, and thence to the eye.

In measuring the angular distance between two bodies, holding the instrument in the plane of the objects graduated, face up, it is necessary to direct the

telescope to the left-hand object, the two reflectors bringing in the image of the other. But if one of the objects is faint, owing to the loss of light in two reflections, it may not be possible to see it if it is the right one, in which case it will be necessary to look at it directly, turning the graduated face down to bring the left-hand one into the field of view.

The advantages of the pocket sextant are its portability and accuracy, and the fact that it affords the means of solution of many important problems. The objection to its use in triangulation has been stated. With an extemporized artificial horizon, as a pail of water, it gives an altitude. The larger form is one of the most generally valuable instruments known. It affords data for correcting timepieces, for computation of latitude, and even gives a rude longitude.

If the sextant be set to read 90°, the glasses make an angle of 45° with each other. Looking through the telescope along any line at any object, the image of a second object, whose direction is at right angles to the line of sight, will be seen coinciding with the first. Hence we may lay off a perpendicular to any given line, by sending a signal nearly the proper direction, and signing it to change position till its image is seen above. This is the use of the optical square, which has two glasses inclined to each other under an angle of 46°.

CHAPTER IV.

PLANE TABLE—MEASUREMENT OF DISTANCES.

A PLANE table consists of a board to bear the paper, a tripod to furnish a support, and the intermediate arrangement of different constructions, serving to level it. In Fig. 24 we have a representation of one about 16 inches square, having its upper edge rabbeted to receive a boxwood frame, which, being accurately fitted, can be placed on the board in any position with either face upwards. This frame is intended both to stretch and retain the drawing-paper upon the board, which it does by being simply pressed down into its place upon the paper, which for this purpose must be cut a little larger than the board.

One face of the frame is graduated from zero to 360°, about the middle point of the board as a centre, in order to make the instrument capable of measuring angles. The reverse face of the frame is usually divided into equal parts, as inches and tenths.

G is a compass-box, let into one side of the table by a dovetail joint, and held in place by a milled-headed screw, so that it may or may not be used at pleasure. The compass facilitates the putting of the table in po-

sition, and serves as a check upon the accuracy of the work.

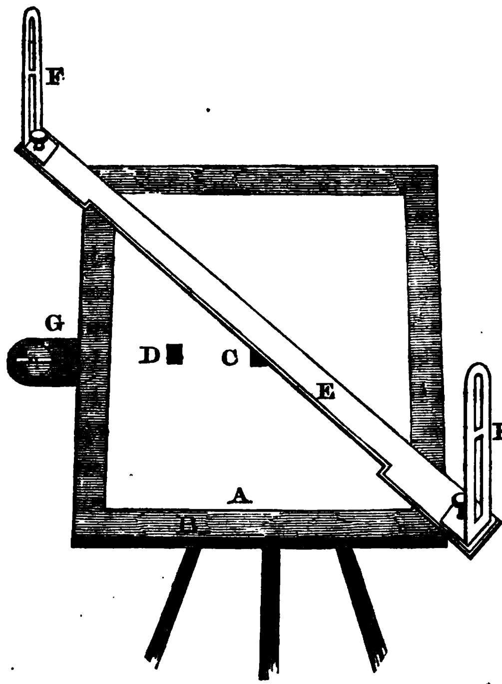


Fig. 24.

The ruler, or index E, is of the length of the diagonal of the table, is of brass and about two inches broad. It has a sloping or fiducial edge. A sight vane, F, is fixed perpendicularly at each extremity, and the eye placed at one of them; the vertical hair in the other, being made to bisect an object, serves to direct the

line of vision. The flat surface of the index is often covered by useful scales, as lines of equal parts, chords, etc.

The arrangement between the table and tripod consists generally of parallel plates with screws, like the spirit-level, or ball and socket, for the purpose of levelling, and the table is levelled when a small detached level retains in any position on the board the bubble at the middle of the tube.

One method of putting on the paper is to dampen its under side, and lay it on the board, confining it by pressing the frame into its place. The paper shrinks in drying, and affords a smooth surface. It is objected to this, that the paper is easily affected by hygrometrical changes in the atmosphere after undergoing this process, and some prefer to put the paper on dry, keeping it as smooth as possible, and confining it as before by the frame.

The survey may be so large as to require several sheets of paper, in which case the old sheet is removed when filled and a new one is substituted, which, however, should contain two stations in common with the first, in order that the two sheets placed side by side, the projections of the same stations in both coinciding, may make a continuous map. The line on the new sheet should be so placed, in reference to the direction in which the work is to be extended, as to take in the maximum quantity of work.

Simple modifications of the plane table are prefer-

red by some. A plain board of well-seasoned soft wood (pine or cedar), with compass, the whole made so as to fit on the staff or tripod, is all that is essential. The paper here may be pasted on, affording protection against expansions or contractions; when one board is filled up, replace it by another, and after the whole work has been done, a general map may be constructed from the several parts.

Instead of sight-vanes, a telescope is sometimes mounted, to direct the line of sight. It has a reticle in the principal focus of the eye-glass.

The plane table is in position in reference to previously determined points, when one line on the sheet is parallel to its representative in the triangulation; and this must be brought about at every station, either by aligning a pencil line by the index on the stations which it joins, or by the compass-bearing.

Let us see how, by means of this instrument, we may form the plan or horizontal projection of the sides of the triangle, R S P, Fig. 25. We first set up the plane table at R, and level it. Assume a point on the paper directly above the point R, as the projection of R, and insert a needle at this point; then direct the line of sight to S and P in succession, and draw, with a pencil, the lines *r p* and *r s* in their directions. Then measure the distance R S, and, taking from the scale of equal parts a distance assumed to represent the line R S, lay it off from *r* to *s*, and *s* will be the projection of S on the paper. Transport the instru-

ment to S, set it up level, and place it so that *s* is vertically above S, and turn it till the pencil line *r s* coincides in direction with R S, which will be the case when the R is seen bisected by the vertical hair of the sight-vane, while the edge of the index coincides with *s r*. The table is now in position. Set up a needle at

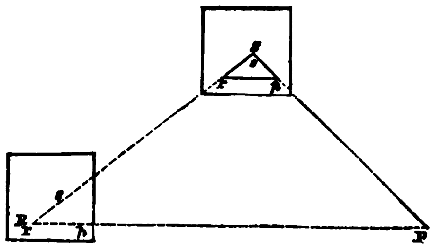


Fig. 25.

s, and turn the index about it till P is brought into the line of sight, then draw the line *s p*, which will intersect the line *r p* in the point *p*, which corresponds to P. The triangle *s p r* is the plan of S P R. By means of a protractor the angles may be measured; and the distances *s p* and *r p*, taken up by dividers and applied to the scale of equal parts, will give the lengths of the sides S P and P R, so that we have a means of determining inaccessible angles and distances.

The point *s* is placed vertically above S by means of a plumb-line, fastened to the lower surface of the table just below *s*, and this is facilitated when the instrument has a clamp screw, and tangent screw for

small changes of position of the table without displacing the tripod.

We will now proceed to exhibit some of the applications of this instrument, and the first will be to determine projections of points by the method of *intersections*. We will suppose two stations, A and E (Fig. 26), the distance between which has been measured and reduced to the horizon. We draw upon the paper the line *a e* to represent A E, taking its length from the scale of equal parts, as before. Then set up the instrument at A, level it, and bring the point *a* vertically above A by means of a plumb-line, and make *a e* coincide in direction with A E, as before. Set up a pin at *a* and turn the index in succession on the stations B, C, D, keeping it all the time in contact with the pin, and draw according to the successive positions of the index, and along its edge, the lines *a b*, *a c*, *a d*, which will contain the projections of B, C, D, and will represent the projections of A B, A C, A D, respectively. Transport the table to E, set it up as before, *e* vertically above E, and *e a* having such a direction that, when the index is placed on this line, A will be in the line of sight. Set up a pin at *e*, and direct the index, always touching *e*, upon B, C, D, drawing in succession the lines *e b*, *e c*, *e d*, to represent the projections of E B, E C, E D. The points of intersection of corresponding lines through *e* and *a* give the positions of B, C, and D on the plan. For instance, the intersection of *a b*

and *e b* corresponds to B, of *a c* and *e c* gives C, and so on. To avoid confusion and error, it would be well to write while at A, along each line drawn, the name of the station towards which it is directed, and do the same at E. By joining the points thus determined, we have a representation of the outline in plan, upon the scale that has been selected.

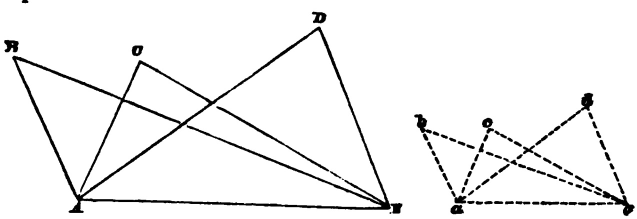


Fig. 26.

In the second method, the instrument is set up at each station, and the distance between each pair of successive stations measured. It is a longer method than the preceding. The table is first set up at A (Fig. 26), in conformity to the principles previously laid down, and the index directed to E, and a corresponding line *a e* drawn on the paper. The distance A E is measured, from the scale a distance *a e* is taken to represent A E, this is laid off from *a* to *e*, and *e* becomes the projection of E. The instrument is set up at E, and put in position, as before described, the index directed towards B. Draw the indefinite line *e b*, measure E B, take its representative from the scale, lay it off from *e*, and the other extremity of this length represents B. This operation is con-

tinued, and will be verified if, on returning to A, the polygon is found to close exactly.

This method is practised in representing winding roads, the banks of a stream, and in thickets of woods.

A third method consists in setting up the table at but one station, usually selected in the interior of the figure which it is desired to represent in plan, and from which all the other stations are visible, as at C (Fig. 27).

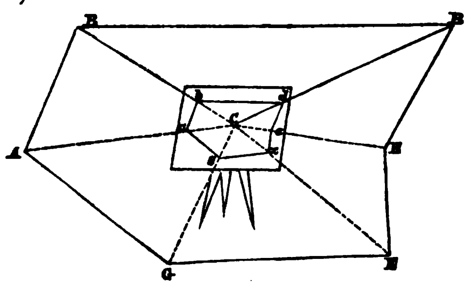


Fig. 27.

The index is directed in succession along C A, C B, C D, and *c*, and the corresponding lines drawn in pencil C *a*, C *b*, C *d*, and *c*. Then the distances C A, C B, C D, etc are measured, and their representatives taken from a scale of equal parts, and laid off in their proper directions, giving *a*, *b*, *d*, and *c*.

The compass affords facility in putting the plane table in position. Let us suppose it to be in a rectangular box: then, at the first position of the table, place the compass-box on the table and turn the box till the needle comes to rest in a direction parallel to

the longest edge of the box, and draw a pencil mark along this edge as a ruler. At the next station, when the table has been set up, place the long edge of the compass-box along the same right line, and turn the table till the magnetic needle resumes its position parallel to the edge; when this takes place the table is in position for further observation. This is of easier execution than the previous method, which consists in making the lines on the paper lie in the vertical planes through the corresponding ones on the ground.

If there should be any local cause to derange the magnetic position of the needle more at one station than another, it is evident that the compass would assign an erroneous position to the instrument.

If the compass is always fixed in the same place as represented in Fig. 24, it will be sufficient to establish the position of the plane table, so that the needle indicates the same bearing as at the previous station.

To locate a particular point, as a bend in a road, set the instrument up at this point, and turn it till the compass indicates the same reading as it did at the several stations already plotted on the board, when the table will be in position. Set up a needle at one of the stations and direct the index (without moving the table), its edge against the needle, towards the station whose locus is at the needle; draw a line along the index edge, on that part of the board where the point sought is likely to fall; take up the needle

and fix it in the projection of another known station, and, as before, direct the index to this station, and draw a line; its intersection with the first line will be the position of the observer in projection. For verification, it would be well to use a third station in the same way, and the three lines should have a common intersection.

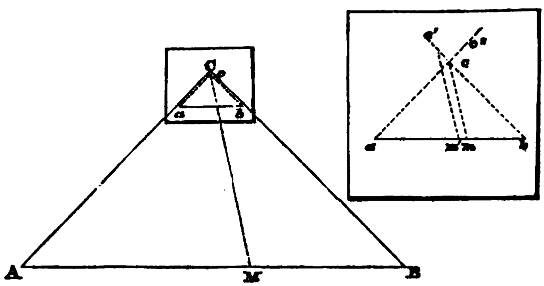


Fig. 28.

If we have given the projection of two points, one of which is inaccessible, we may determine the position of a third point which is accessible. Let *a* and *b* represent the projections of A and B, the latter being inaccessible. Set up the table at A in position by sighting B, turn the index to C and draw *a c''*. Take the table to C, and put it in position by using the line *a c''*; erect a needle at *b* and turn the index to sight B, and draw along its edge *b c'*; the intersection with *a c'* is the projection of C.

If both the known points be inaccessible, and a point on their alignment and between them is acces-

4*

sible, we may still fix the projection of the third accessible point C. For this purpose, set up the table at M, on the line A B, and place the table in position by this line, and assume a point m' to be the projection of M. Sight C and draw along the index edge the line $m'\ c'$. Go to C and align $m'\ c'$ on M C, then $a\ b$ is parallel to A B. Place the edge of the index on a and sight A; do the same for b, and draw the corresponding lines; their intersection is C in projection.

The three-point problem has for its object to determine the position of a point from which three known, but inaccessible points are visible. Let g, m, d, be

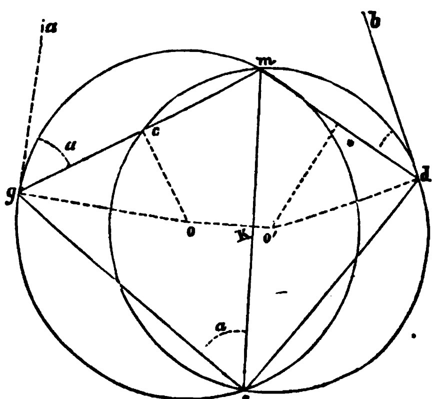


Fig. 29.

the projections of the three points, and s the projection of the point required. At S measure the angles G S M and M S D, and through g and d draw two lines $g\ a$ and $d\ b$, making $a\ g\ m$=G S M, and $m\ d\ b$

$= M\,S\,D$. Then at g and d respectively, erect perpendiculars $g\ o$ and $d\ o'$ to $g\ a$ and $d\ b$, and at the middle points of $g\ m$ and $m\ d$, erect perpendiculars $c\ o$ and $e\ o'$; from the points of intersection o, o', as centres, describe $g\ m\ s$ and $d\ m\ s$, their intersection is S, since $g\ s\ m = a\ g\ m = G\ S\ M$, and $m\ s\ d = m\ d\ b = M\ S\ D$, subtending equal arcs.

To construct the angles $a\ g\ m$ and $b\ d\ m$, with plane table set it up at S, placing g over S, and turn it till $g\ m$ is in the vertical plane of S M; then sight G by turning the index about g, and draw a line along the index; this is $g\ a$; and in a similar manner the other angle is laid off again.

The problem may also be solved by successive approximations, by setting the plane table at S, as nearly in position as possible, and through the projections of the points sighting the points themselves. This gives three lines which intersect in a point where the table is in position, and by successive trials nearer approximations are made.

Take a sheet of transparent paper, stretch on the plane table, and through any assumed point draw three lines, making with each other the measured angles at S; then superpose this sheet on the map so as to make these lines pass respectively through the points to which they refer; prick their point of intersection with a needle, and this is the required point on the map. This is a problem of frequent use in surveying, and occurs in the use of the sextant.

The preceding illustrations of the use of the plane table are sufficient to show its use in surveying, both for measuring angles and for plotting a projection of a series of points. It is chiefly used in the filling in of details, although, when it has a graduated limb, compass, and telescope, it is available for a wider range of usefulness.

For a rapid survey, such as a reconnoissance in the presence or vicinity of the enemy, the following is a simple and portable construction of the plane table. It is composed of several rules of equal length and breadth, held together by being pasted to a sheepskin or strong cloth. To make a plane table, they are unrolled and held in the plane by means of two similar rulers turning about one extremity, with a small hook fastened at the other. When not in use, it may be folded up and carried in the pocket or holster. It may be fitted to an iron-pointed staff. An index may easily be made for it, provided with needles instead of sights.

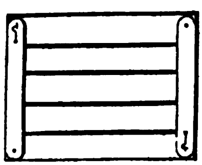


Fig. 80.

MEASUREMENT OF DISTANCES.

The chain is one of the most obvious devices for this purpose. It is found of various lengths, but, for purposes of topography, fifty feet is as convenient as any Ten pins usually are used in connection with it, and are taken by the chain-man in advance, who marks the extremity of the chain by fixing one in the ground,

which is picked up by the rear man. The rear man should keep his partner in the alignment of the two stations. The forward chain-man may also fix the position of the rear man on the line with the back station.

The chain should be well stretched upon the ground, and when the latter is not level, it is necessary either to keep the chain horizontal, or to take the inclination of the chain when stretched on the ground, in order to reduce the measured distance to the horizon. The latter is the more exact method, if carefully carried out, as in the former case the chain will always be more or less curved, thus giving too great a distance. The chain is used for the measurement of bases in topography.

It may be necessary to stake out the line to be measured, when the extreme stations are not visible from all points of the line.

The chain-men may establish themselves on the line connecting two visible stations, as follows: Having placed themselves facing each other, approximatively on the line, one causes the other to move till he covers one station; the second, in turn, fixes the other so as to cover the other station; and the process is repeated till each covers the station in front of the other.

The manner of using the chain is too obvious to need description.

Odometer.—This consists of a small brass circular box, containing a series of cogwheels, which regulate the motion of an index on a dial-plate upon its exte-

rior, which records the number of revolutions of a wheel to which the box is attached by straps. The length of the perimeter of the wheel, multiplied by the number of revolutions, will give the distance passed over. This distance is generally too great, since roads are rarely straight and level, and should be reduced by from one-fifth to one-tenth, depending upon the character of the country. It is obviously a comparatively rude approximation, but is often of considerable value.

When the rate or pace of a man or horse has been determined, it may be used for measurements of distance, which should also be reduced from one-tenth to one-fifth, depending upon the undulations and tortuousness of the route pursued.

The velocity of sound in a calm, clear atmosphere, at 32° Fahrenheit, is 1,090 feet per second; for a higher temperature add one foot for each degree above 32°. A gentle breeze will increase or decrease the velocity about 10 feet, according as it blows in the direction in which the sound comes to the ear, or the opposite. A gale will make a difference of 20 or 30 feet, and a very high wind of 70 or 80. When the wind blows perpendicularly to the sound route, the velocity is supposed to be unaffected; when obliquely, the change of velocity will be sensibly equal to the estimated velocity of the air multiplied by the cosine of the inclination of its path to the sound route.

The time in seconds between the flash of a gun and

the hearing of the explosion, multiplied by the velocity as above determined, will give the distance between the gun and ear.

The distance of an object whose height is known, may be determined in the following manner: Take a narrow, smooth strip of wood, several inches in length, and graduate it by divisions, 16 to 20 to the inch. It is to be held vertically between the thumb and forefinger, the arm extended. Its distance from the eye when thus held must be known, and may be supposed constant. It is determined in this manner, viz.: measure off on a level plane a distance of, say fifty yards, and at its extremity set up a staff in a vertical position; hold the strip of wood as above described, so as to cover the whole or portion of the staff, the foot just visible over the thumb nail, and mark the point covered by the top of the strip; measure its height above the ground, and represent it by a; call the measured distance (fifty yards) b, and the portion of the graduated strip above the thumb nail c, then the distance of the latter from the eye is $\frac{bc}{a}$, and is known; call this distance d.

To determine the distance of a body whose height, H, is known, cover it as above, and

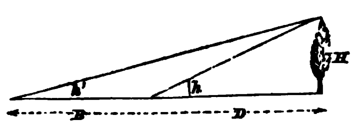


Fig. 31.

call h the length cut off, on the graduated slip; then $D = H\frac{d}{h}$ to within perhaps $\frac{1}{50}$ of its true value.

When H is not known, measure off in a direction opposite to the object a distance, B, equal to the estimated value of D. From both positions apply the strip of wood, as above described, and call h' the last space cut off; the $D=B\frac{h'}{h-h'}$ to within $\frac{1}{15}$ or $\frac{1}{20}$ if B is nearly equal to D, and h is not less than one inch. This may be applied in finding the width of a river. The degree of approximation is given on the authority of French officers. It should be determined by each one for himself.

A stadia is used for the same purpose in connection with a graduated staff. It consists of a telescope with two horizontal hairs in or near the principal focus of the eye-glass. It is important that the image of the staff should fall upon them and be contained in the same plane, and, of course, at the same distance from the eye. These hairs are fixed in a diaphragm, and together they constitute a reticle. As different eyes require waves of different curvature, or, in other words, as some see best when the waves entering the eye are divergent, others when plane, and others when they are converging, it follows that the image and reticle must, for these different persons, be at different distances from the eye, and hence the angles at the eye, subtended by the distance between the hairs, are different. This requires each observer to graduate his own staff. The rod is graduated by trial. Let us suppose the first distance to be 300 yards; the staff is held

vertically, the telescope directed so that the lower wire covers a transverse black mark on the staff; the point covered by the upper hair is marked by another transversal, and is numbered 300 yards. Other points of the scale are determined in the same way. The distance of a point is determined by sending a man with the staff to the place; he holds it vertically; the number corresponding to the point covered by the upper hair is the distance in yards, the telescope being directed as before. It is obvious that, if the point be occupied by any object whose height we know, its distance becomes known without the use of the staff.

There are other forms of these instruments, as a hollow tube, with a small aperture for the eye, and in the interior two parallel hairs, which are movable by means of a micrometer screw. This probably affords as good results as the telescopic arrangement, and better than the graduated strip just described. In the telescope, too, a movable reticle is sometimes applied. All these methods should be verified by actual measurement of different distances. Some persons estimate distances with an accuracy that seems wonderful. It is a natural gift, but may be greatly cultivated by practice. It is a valuable acquirement, and finds important application in making a sketch of a position in presence of the enemy, where one is not able to use any of the ordinary methods.

CHAPTER V.

LEVELLING INSTRUMENTS AND LEVELLING.

Levelling instruments may be divided into two classes, the uses of which are generally quite distinct. The first gives the direction of the line of apparent level; while the second is used to measure the inclination of the visual ray to the apparent level, and both are founded upon one of the following principles:

1. Any confined fluid or fluids acted upon only by their weight, as modified by the centrifugal force due to the rotation of the earth about its axis, will arrange itself so as to make the free surface, or the surface common to the two fluids, everywhere perpendicular to the direction of the weight. This surface may be regarded as coinciding with the tangent plane of the horizon.

2. That a plumb-line assumes a vertical position.

The most accurate instruments involve the first principle, and depend upon a *spirit-level*, which consists of a tube of the form of an arc of a circle, partially filled with alcohol or ether; the remaining space, being filled with air, takes the appearance of a bubble, which always occupies the highest portion of the tube.

WATER-LEVEL.

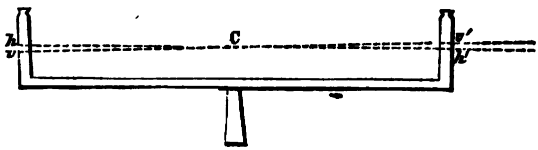


Fig. 82.

This instrument consists of a cylindrical brass tube, bent at its extremities so as to present two arms at its right angles to its length. In these are set two glass vials. The tube is mounted on a tripod, and admits of a motion around the vertical axis, so as to make the circuit of the horizon. The tube is filled with water from one of its extremities, till its upper level is halfway or more up the glass vials. The water may be colored to make it more distinct. When it comes to rest, the upper surfaces in the two tubes have the same level, and, if we look tangent to these surfaces, the visual ray is horizontal. The vials being small, however, the upper surfaces will be curved, and hence there is some chance of committing error. However, a tangent to these curved surfaces at the highest points is horizontal, or a line connecting the points where the upper surface touches the glass in each tube is horizontal. It is usual to stand off some distance, so as to lessen the error of observation.

The vials should be of the same size; if not, the line of level will be different for different positions of the tube, unless the axis of rotation is vertical and the

tube perpendicular to it, which generally is not the case. If we suppose the line of sight to be not horizontal, the error of level will be greater as the distance is greater. Hence it is usual to limit the use of this instrument to distances not exceeding fifty times its length. For this limit the error is about four inches, supposing the eye to err $\frac{1}{16}$ of an inch on each vial. In the hands of an unskilful observer there is not nearly so much liability to error as would arise from an imperfect adjustment of the spirit-level. This instrument is of so obvious and simple construction, that almost any one is able to make one. This, and the fact that it adjusts itself, that the surface of the water in the vials is always level, constitute many evident advantages.

The Y spirit-level is represented in Fig. 33; it consists of an achromatic telescope mounted in Y's, and has a reticle in the principal focus of the eye-glass. The reticle consists of two spiders' lines, at right angles to each other, fastened at their extremities in separate slides. The object-glass is mounted in a separate tube *a*, which is made to move in and out of the main tube, by turning the milled-headed screw A. The tube *c c*, supporting the spirit bubble, is fixed to the underside of the telescope by a joint at one end; at the other is a capstan-headed screw, which enables one to set the axis of the tube parallel to the line of collimation. This line is determined by joining the intersection of the cross hairs and the optical centre of the

object lens. One of the Y's is susceptible of a vertical motion by turning the screw B, in order to make the line of collimation perpendicular to the vertical axis, or axis of rotation.

Between the two supports is a compass box C, which enables us to take bearings at the same time. This is not an essential part of the level, and many instruments are without it.

O O is a brass plate through which four levelling screws (two of which are seen in the figure) turn in sockets in the lower plate, while their heads press

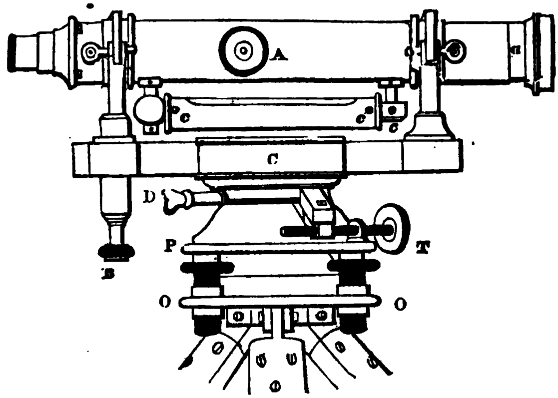


Fig. 83.

against the upper plate, P. D is a clamp-screw which closes upon the axis a collar, preventing all motion when the level is pointed for observation. A slight motion may, however, be impressed by the tangent screw T.

The object of the motion of the object lens is to throw the image on the cross hairs of the reticle. The eye-piece also admits of motion to and fro in the tube, and should be adjusted to bring the cross hairs out distinctly. Then the telescope being directed, the screw A is turned till the image is seen distinctly.

It should have been observed that the cross hairs may be slightly moved by small screws near the eye end, one of which should be loosened before the other is tightened. Each admits of motion separately, two of the screws moving the slide which contains the vertical hair, and the other two the horizontal.

There are three adjustments. 1. To place the intersection of the spider lines on the axis of the tube. 2. To make the axis of the level parallel to the line of collimation. 3. To make the axis of the level and the line of collimation perpendicular to the axis of rotation.

First adjustment. Direct the telescope to a small well-defined object, causing it to appear on the intersection of the cross hairs; then, turning the telescope half over as it lies in the Y's, observe whether this coincidence continues; if so the adjustment is perfect. If, however, the horizontal hair appears above or below the point, loosen one of the screws which move its slide and tighten the other, so as to carry the hair over half the estimated interval. Redirect the intersection on the object, and if the distance has been correctly estimated, the object will be seen on

the horizontal hair as the telescope is turned in its bed. If not, another, and perhaps a third, trial will be necessary to complete the adjustment. A similar process will correct the adjustment of the other hair, and the intersection will remain on the axis.

Second adjustment. Open the Y's, and turn the telescope till it is over two of the levelling screws, and by means of the latter bring the bubble to the middle of the tube. Take the telescope up and turn it end for end, and if the bubble returns to the middle of the tube the axis of the level is horizontal. If not, the bubble is brought to the middle, half by the levelling screws and half by the capstan-headed screw. A new trial is made, and, if necessary, repeated approximations till the bubble remains in the middle; the axis of the level is then horizontal. Revolve the telescope in the Y's slightly, and if the bubble remains in the middle, the axis is parallel to the line of collimation; if not, the axis is moved by the screws *e*, loosing one and tightening the other, and by successive approximations the axis is brought into the same plane with the line of collimation. Re-examine the first part of this adjustment, to see whether it has been disturbed.

Third adjustment. Place the telescope over two of the levelling screws, and bring the bubble to the middle, by screwing one and unscrewing the other. Turn the telescope about the vertical axis 180 degrees, bringing it over the same screws; and if the bubble

does not remain in the middle, bring it back half by the screw B and half by the two levelling screws. Then turn the telescope over the other two screws and repeat the process, and when the bubble remains in the middle for every position of the telescope, the adjustment is complete.

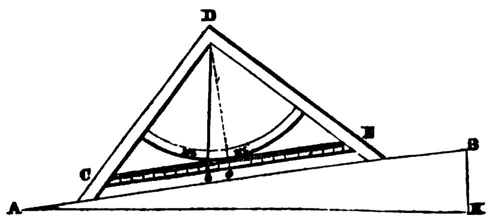


Fig. 34.

The mason's level is represented in Fig. 34, and belongs to the second general class of levelling instruments.

D C E is an isosceles right-angled triangle of wood or brass, the altitude, of course, being equal to one-half of the base C E. When accurately constructed, a plumb-line, suspended from D, bisects the base when the latter is horizontal. To determine this point, place the base on a slightly inclined surface, A B, and note the point *m*, where the plumb-line crosses; then turn the base end for end, and mark the corresponding point *m'*: the point *o*, required, is midway between *m* and *m'*. This is the origin of a linear graduation on C E, extending each way, and dividing each half of the base into equal numbers of

equal parts. For illustration, suppose the number to be one hundred. A graduated circular arc, having its centre at D, tangent to the base and terminating in the sides about the right angle, is sometimes added, having its zero at the point of crossing of the plumb-line when the base is horizontal, the graduations increasing in each direction. To apply it to measuring the slope of A B, place it in the position in the figure, and note on the arc or base, the number where the plumb-line crosses. The number of degrees on the arc is the inclination of A B to the horizon, and the number on the base divided by one hundred is the tangent of the inclination. To find the slope, refer to the table of natural tangents. For instance, suppose the number on the base to be twenty; then twenty divided by one hundred is 0.2, and by reference to the table we find the inclination to be 11° nearly.

All this is evident, since *o* D *m* and A B K are similar triangles, and the angle *o* D *m* is equal to B A K. B K is equal to A K × tangent B A K, whence we obtain the difference of level between A and B. It is also apparent that any error in reading the angle *o* D *m*, or its tangent, produces a corresponding error in the value of B K, which increases as A K becomes greater, and hence it is well to limit the use of this instrument to short distances. If the error of estimation on the base is 1-25th of an inch, the error in B K is four inches, provided A K is one hundred times *o* D.

A *slope level* consists of a spirit bubble, attached to a flat brass plate by a hinge, and of a circular graduated arc, having its centre at the hinge. When the plate is horizontal, and the spirit-level resting on it, the bubble stands at the middle; but when the plate is inclined, it is necessary to raise one end of the spirit-level to bring the bubble to the middle. The angle through which it is revolved is equal to the inclination of the slope.

Burel's Reflecting Level.

This instrument, represented in Fig. 35, consists of a cube of copper, of which the edges are about one inch in length. To one of the faces is attached a ring, A, by means of which it is held in the hand. There is a screw and nut, B, which serve to move the point of suspension. The face, E F G H, is a mirror, in

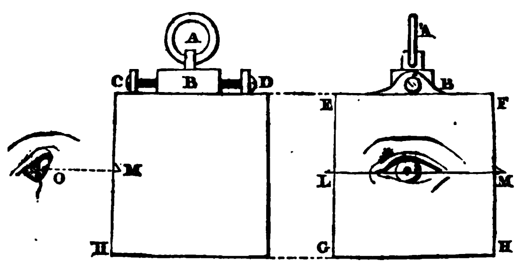


Fig. 35.

front of which is stretched a fine thread, parallel to the base, and fastened at the points L and M, which

project beyond the face of the cube. The plane of the mirror should be vertical, and the line L M horizontal. Then, to use it, hold it so that the line L M bisects the pupil of the eye, when the thread and its image appear as one, and the plane passing through the eye and the thread is horizontal. By means of the points L and M, indicate to the rodman in which direction to move the vane so as to bring its middle line into the horizontal plane, through the eye. The difference between the height of the eye and the reading of the level-staff is the difference of level. We may eliminate the height of the eye, by using another station and noting the reading of the level-staff again; the difference between the two readings is the difference of level between the points occupied by the level-staff. Keeping the vane at the same height, let the rodman occupy different positions, such that the vane is always in the horizontal plane through the eye. These points are on the same level, and are points of a horizontal curve. This indicates an application in laying out the principal horizontal curves.

To ascertain whether the mirror is vertical, take a position in front of a vertical wall S T; let F H be the mirror; mark the intersection p of the wall with the plane through the eye and the points L and M; then turn the back to the wall, and again place the level at the height of the eye, F′ H′ being the new position of the mirror. The intersection of the wall with the plane of the eye and L M, which must always be nor-

mal to the reflector, now passes through p', and may be seen by looking obliquely in the reflector. If p and p' do not coincide, the reflector is not vertical, and must be moved through an angle equal to F′ L N. To do this, mark P halfway between p and p', and turn the screw C D, till this point is seen in the normal plane through the eye. Reversing the direction of the eye, it should still appear in this plane.

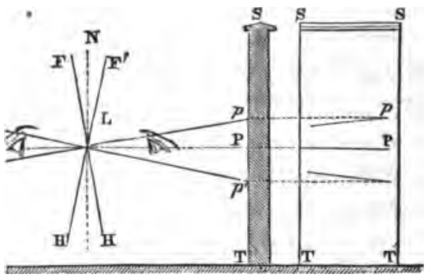


Fig. 36.

This instrument may be held in the hand, or suspended from a stake planted in the ground. It is very portable and useful. It is the invention of a French officer.

A rule, a few inches long, suspended from its centre of gravity, furnishes a horizontal line.

Captain Livet's Level.

It consists of a rule, ten inches long, provided at each extremity with a bubble and a sight of copper, one of the latter pierced in two points v v'; the other, D, has a rectangular aperture, in the largest

dimension of which is stretched a thread, which, with v or v', determines the plane of sight. D is graduated into parts, each one of which is equal to $\frac{1}{100}$ part of the length of the rule C D. The whole may be mounted on the plane table, and thus

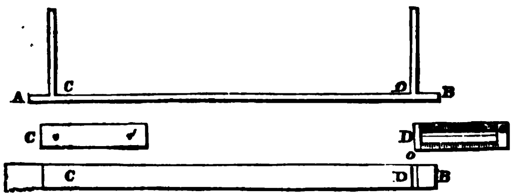


Fig. 87.

with the same instrument fix the horizontal projections of points, and determine their difference of level. To use it, if the object to be observed is above, apply the eye to the lower aperture v, and slide a strip of paper along D till the object is seen, the visual ray grazing the edge of the paper; the number of divisions read from the ascending scale, divided by one hundred, is the tangent of the angle at the eye, and this ratio, multiplied by the horizontal distance of the object, gives the altitude of the object above the eye, and this, increased by the height of the eye, is the altitude above the ground, at the position of the instrument. When the object lies below the horizon of the observer, the upper aperture is used for the eye, and the proper number of divisions is taken from the descending scale, the zero of which is on the level with the upper eye aperture.

Burnier's Clisimeter or slope-level is not so accurate as the preceding, but has the advantage of being used in the hand, and requiring no mounting. Fig. 38. It consists of a box, in which is mounted a circular graduated arc, having its centre at C, just above the centre of gravity of a needle, represented in dotted lines, which always remains horizontal, if we neglect the small oscillations it performs when disturbed. When at rest it is horizontal. On one of the faces of the box, and at the height of C, are two notches, V and Y, which determine the line of sight, which is horizontal when the needle stands at zero.

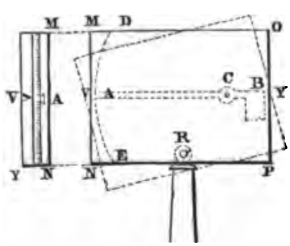


Fig. 38.

Then, to measure a vertical angle, it is only necessary to turn the box, till the line V Y has the proper direction, and read the angle shown by the needle. The box may be mounted on a staff, as represented in the figure.

The needle might have been made so as to have its centre of gravity at the middle point of its length; but the graduations would have been more minute, since the radius of the arc would have been smaller. The only adjustment of this instrument is, that the line of sight should be horizontal when the needle stands at zero.

For levelling purposes, the French adapt to a compass box a vertical graduated limb and telescope. For

great accuracy, we may use the theodolite or spirit-level; and for less strict purpose, some one of the several devices that have been described.

In connection with the Y level, a rod is used, which is made of different constructions. It is usually of two parts, each about six feet in length, which slide together for transportation; but, when necessary, they may be extended, giving a rod about twelve feet in length. It is graduated into feet and tenths. It is provided with an iron vane, which may be moved up and down. The middle line of the vane is made to intersect the prolongation of the line of collimation of the level. It is rendered conspicuous by painting portions of the vane in different colors. The rod is sometimes provided with a vernier.

A common semi-circular protractor may be used for levelling purposes, after attaching a plumb-line to the centre. To ascertain the difference of level between A and B (Fig. 40), standing at A, hold the protractor at the height of the eye, in a vertical plane. Hold the zero of the graduation towards the eye and look along the edge M N, changing its inclination till the point B is seen. The plumb-line falls on a division of the graduation which indicates the zenith

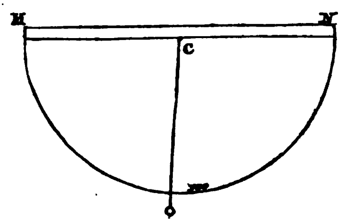


Fig. 39.

Fig. 40.

distance of B. To facilitate the observation, place one hand under the limb, so as to hold the plumb-line in position while you note the reading.

It is sometimes convenient to use, in connection with the protractor, a scale of the following description, Fig. 41. Assume a line M, N, as a horizontal,

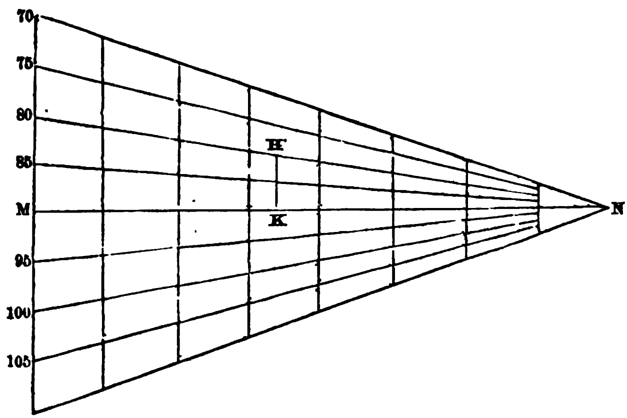


Fig. 41.

and lay on either side, lines making angles with it of 5°, 10°, etc.; their zenith distances then are 85°, 80°, etc.; and those for below M N, 95°, 100°, etc. Through M, erect a perpendicular, and draw a number of lines parallel to it. Take from the plan the horizontal distance in feet from A to B, and lay it off on the scale, and let N K represent it. Draw through K a perpendicular line to M N, and terminate it at H, on the in-

clined line which corresponds to the observed zenith distance. Then K H represents the difference of level between A and B, according to the scale of the plan. Applying it to the scale, we ascertain the number of feet required. If the zenith distance falls between two inclined lines on the scale, we easily approximate.

Take a ruler of wood A B, attach a thread to its extremities, and determine the point of suspension C, which makes A B horizontal. Holding it at the height of the eye, and looking along it, the line of sight is horizontal. This is referred to in a subsequent part of the subject.

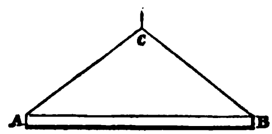


Fig. 42.

Levelling.

We have regarded the earth as a sphere in determining the horizontal projections of points, and, as our levelling operations do not require its ellipticity to be taken into account, we still consider it spherical.

A line is said to be level when it is parallel to the surface of the ocean at rest; every point of the line is then at the same distance from the centre of the earth, and the line is an arc of a circle. If two points are at unequal distances from the centre of the earth, there exists a difference of level, which it is the object of certain instruments to determine.

These instruments determine the tangent A B″ to the first element of the curve, and give a difference of

level B B″, instead of B B′. The line A B″ is called the apparent level, and the arc A B′ the true level. The apparent difference of level between A and B is B B″, the true is B B′=A A′; hence, the instrumental result must be corrected by adding a quantity equal to B′ B″. This is the correction for curvature of the earth's surface. For a few hundred yards this difference is small, and may usually be neglected; while beyond this distance, whether it should be taken into account or not depends upon the accuracy of the instrument used, and the object of the survey.

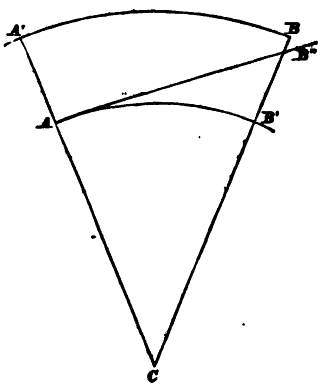


Fig. 43.

NOMENCLATURE.

C, Centre of the earth; A B′, a great circle of the earth; A′ B, an arc parallel to A B′.

To find B′ B″, we recall that the tangent is a mean proportional between the secant and its external part; hence, denoting the radius of the earth, A C, by R, the horizontal distance between the points by K, and B′ B″ by h, we have

$$K^2=h\,(2\,R+h) \quad \text{or} \quad h=\frac{K^2}{2\,(R+h)};$$

and, neglecting h in the denominator, as being insignificant compared with 2 R, $h=\dfrac{K^2}{2\,R}$.

For another distance, K′, we have $h' = \frac{K'^2}{2R}$; hence, $h : h' :: K^2 : K'^2$; or, the differences between the true and apparent level are proportional to the squares of the horizontal distances between the stations.

By assigning different values to K, and substituting for 2 R the mean diameter of the earth, a table of values for h may readily be constructed. If K is one mile, h is very nearly eight inches; for two miles, four times eight inches; for three miles, nine times eight inches; for half a mile, a quarter of eight inches. Or we may adopt this formula: h in feet $= \frac{2 K^2}{3}$, K being expressed in *miles*.

It is possible, however, to eliminate this correction for curvature. Let A, Fig. 44, be the position of the spirit-level, equidistant *horizontally* from the points B′ and D″. Then B″ D″ is the apparent level, and B′ D′ the true. D″ is on the apparent level of A, and B′ is below it, by a distance equal to B′ B″ equal to D′ D″, but the latter is the true difference of level, and is equal to the apparent difference. Hence, if the instrument be placed so as to be equidistant from

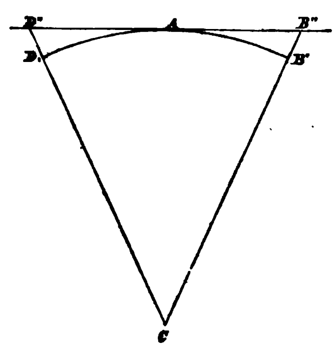


Fig. 44.

the two points, there is no correction for curvature; and this is a general rule to be observed in all levelling operations.

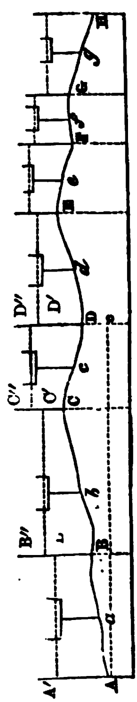


Fig. 45.

To explain the actual steps to be followed in using the Y level, let Fig. 45 represent a section of ground to be levelled. A, B, C, and D are the positions of the levelling staff, and *a*, *b*, *c*, the different positions of the level.

First set the instrument, supposed adjusted, at *a;* place the telescope in succession over each pair of the levelling screws, bringing the bubble to the middle of the tube. The rod-man is sent to A, holding the staff vertically; the telescope being turned upon him, and the glasses adjusted to distinct vision. The observer finds that the vane is either too high or too low, and, by language or gestures, causes the rod-man to move it down or up, till its middle line is seen on the intersection of the spider lines. The middle of the vane is then on the same horizontal as the line of collimation, and the reading of the rod gives the difference of level between the foot of the rod and the line of collimation.

The rod-man reads the staff, or, if the graduation and figures can be distinguished by the observer, the latter reads and records it. The rod is now sent to B,

the telescope turned to it, and the vane adjusted, as in the previous case, and the level staff read. The difference of the readings, is the difference of apparent level of A and B. B is higher than A, since the *foresight*, that is, the reading of the level staff at B, is less than the *backsight* to A. It is to be observed that the height of the instrument is eliminated.

The level is now taken up and moved to *b*, where it is set up again, with the precautions observed at *a*. The *backsight* to B is taken, and then the *foresight* to C. A similar process is repeated at *c*, *d*, *e*, *f*, *g*.

LEVEL FIELD NOTES.

Stations.	Backsights. +	Foresights. −	Reduced Levels.
	Feet.	Feet.	Feet.
a	7.45	5.60	A and B + 1.85
b	7.75	3.35	B and C + 4.40
c	5.10	7.00	C and D − 1.90
&c.	20.30	15.95	A and D + 4.35

The results of observation are usually recorded by the observer in tabulated form, the backsights in one column regarded as positive, the foresights, as negative. The final difference of level between the extreme positions of the rod-man, is obtained by adding the backsights and foresights separately, and taking the difference of their sums, as is evident from the figure. Since A A′ + B B″ + C C″ diminished by B B′ + C C′ + D D′ is equal to D *o*, which is the difference of level of D and A.

The figure is a profile of the ground, and the man-

ner of constructing points of the curve from the observations, is too obvious for explanation.

The process of levelling is the same with the water-level, and, indeed, the figure represents a level of this kind.

If the stations *a*, *b*, and *c* are equally distant from the points A, B, C, etc, there is no correction for curvature; but when these distances are very unequal, and it is decided to correct for curvature, they must be measured, to give K in the formula.

The example we have taken ought to be sufficient to make evident all other applications, as there is no difference in principle. It is not necessary to place the level on the line between two stations; indeed, both stations may be on the same side of it. In this, as in all other cases, the difference of level is the difference of the readings of the staff in its two positions; and where there are a number of stations, the final difference of level is the sum of the partial differences, regard being paid to their signs whether positive or negative.

The example we have given shows how profiles of ground may be constructed. When the differences of level are inconsiderable, in comparison with the horizontal distances, it is usual to use a larger scale for the former than for the latter.

To find points of the ground on the level of the line of collimation of the Y spirit-level, set the vane of the rod at the altitude of the latter, and find, by

trial, points where the middle line of the vane is seen on the intersection of the cross hairs of the telescope. By this means we may find different points belonging to any horizontal section.

CHAPTER VI.

DETAILED ACCOUNT OF THE PROJECTION OF A SURVEY.

THE operations necessary for making an outline map, containing the projections only of the principal points, are as follows:

1. The selection of the principal points.
2. The selection and measurement of a base.
3. The determination of the azimuth of one side of a triangle.
4. Measurement of the angles and the solution of the triangles by trigonometrical rules.
5. The plotting of the points on the map.

The principal points should be selected, so as most nearly to conform to the conditions referred to in Chapter I. They should be well distributed over the area to be surveyed, and so situated as to insure triangles of favorable form. They may be either isolated trees, peaks, spires, chimneys; and, if no distinguishing feature characterizes a point which it is desirable to adopt, it may be marked by a signal. This may consist of a staff and flag. The distances between these points may be several miles in a survey of eight or ten miles in extent, but, as before stated, reference should be had to the instrument which is to be used

to measure the angles. These points should also be chosen in reference to the facility of determining the positions of as many secondary points as possible; hence, they should be visible from the surrounding parts. Commanding points then would be advantageous.

The base is chosen to fulfil the conditions enumerated in Chapter I. Its extremities are marked by signals, unless there are natural points to mark them. When it is quite undulating, it should be staked out by the theodolite, to enable the chain-man to keep the alignment, and stakes also driven at every change of inclination. The measurement is usually made with the chain, although rods of wood or metal give better results. The chain should be compared with a standard, to ascertain its exact length, and great care should be exercised in keeping the alignment and in stretching the chain. Any error in the base runs through all the triangles, since from it all the primary sides are determined. It is well to remeasure it, if possible. The length of each subdivision of the base is noted separately, and its inclination also. The latter is given immediately by the slope or mason's level. The Y spirit-level or water-level gives the difference of level in feet; and if we conceive a right-angled triangle, of which the hypothenuse is the *inclined*, and the base the *horizontal* distance between the extremities of the subdivision, and the altitude their difference of level, it is evident that the natural sine of the inclination is equal to the difference of level divided

by the hypothenuse, both expressed in feet. The inclination, then, may be taken from a table of natural sines. The horizontal projection of the inclined measured distance is then obtained by the method of Chapter I. The same process is pursued in reference to each subdivision, and the sum of the reduced distances is the base which is used.

The methods of determining the meridian or of obtaining the azimuth of a station are given in the latter part of this chapter.

Each station is visited in succession with the theodolite, and where it is possible to place the instrument in the same vertical line as the centre of the station or signal, it is done; otherwise, each angle must be reduced to the centre of the station. For instance, if a house chimney be selected as one of the stations, it is impossible to establish the theodolite on it, hence it is set up in some suitable adjacent position. The angle measured from this position is erroneous, and must be corrected as follows:

Reduction to the centre of station.—Let C represent the projection of the centre of the station; O, the centre of the instrument; and D and G, points to be observed. The angle measured is D O G, the angle required is D C G; hence, it is necessary to calculate their difference. Measure the distance O C and the angle C O G = y. The angle M, being exterior, is equal to D O G + O D M = D C G + C G O; whence D C G − D O G = O D M − C G O.

The sines being proportional to the opposite sides,

$$\frac{\sin. G}{\sin. y} = \frac{r}{C G}$$

$$\frac{\sin. D}{\sin. C O D} = \frac{r}{d}\text{; whence}$$

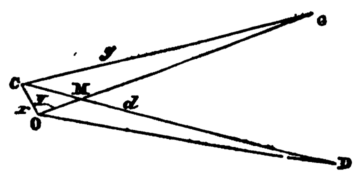


Fig. 46.

$$\sin. G = \frac{r \sin. y}{g}$$

$$\sin. D = \frac{r \sin. C O D}{d}$$

D and G being very small, we may neglect the difference between them and their sines.

$$D C G - D O G = \frac{r \sin. C O D}{d} - \frac{r \sin. y}{g}\text{, and}$$

in order to express the second member in minutes of arc, instead of units of length, we multiply it by $\frac{1}{\sin. 1'}$; hence, $D C G - D O G = \frac{r \sin. C O D}{d \sin. 1'} - \frac{r \sin. g}{g \sin. 1'}$; r and y are measured; d and g known, more or less accurately, from calculation. For further information on this point, reference may be made to the example given subsequently.

Calculation of triangles.—These are resolved according to the ordinary trigonometrical rules. In each triangle, beginning with one in which the measured base is a side, we know one side and all the angles, and we readily obtain the remaining sides. If the sum of the three measured angles should differ from 180°, one-third of the difference is to be applied to each angle, unless there is reason to suppose that an

error has been committed in any particular angle, in which case the difference should be applied to it alone. This difference, however, should be very small, if we use a theodolite.

To Locate or Plot the Points on the Map.

1. For the results of a reconnoissance, it is often sufficient to assume a line for the meridian, and to lay down the base by its azimuth, and proceed to determine the vertices of the different triangles in succession by intersections. In this method, each point depending upon the position of a previous one not accurately determined, errors are apt to increase, as we go further from the base.

2. The second method consists in using a system of co-ordinate axes, the origin of which is at one extremity of the projection of the base. The axes consist of the projections of the meridian and a line perpendicular to it.

In Fig. 47, let A B represent the base; Y Y′, the projection of the meridian and one of the co-ordinate axes; and X X′ the other. The length of the base and the azimuth of A, which is the angle of A B Y, being known, we have for the co-ordinates of A, which are respectively $x =$ B P, and $y =$ A P, B P $=$ cosine of A B P $\times$ length of base, or, what is the same thing, B P $=$ sin. A B Y $\times$ length of base. Similarly, A P $=$ cosine A B Y $\times$ length of base.

To construct the projection of A, lay off from B, the co-ordinate $x =$ B P on the axis of X, and on the axis of Y a distance, B H, equal to A P, and complete the rectangle, as represented by the dotted lines. Their intersection determines the desired point. A similar process determines the other points.

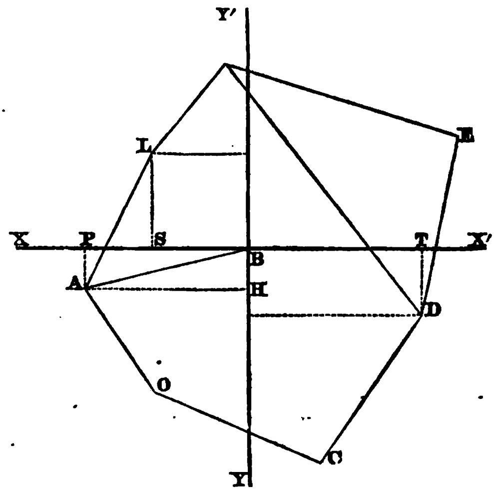


Fig. 47.

It is important to pay attention to the signs of the co-ordinates. If x be assumed as positive for points to the east of the origin, it must be negative for all points to the west; and if y be positive for points north of the origin, it must be regarded as negative for points south of the origin. For instance, for the points A and D, the signs of x are different, while

those of y are the same. For A and L, the signs of x are the same, while those of y are different.

The remaining part of this portion of the survey consists in determining the projections of the secondary points, which, as has been already stated, is done mainly by intersections, and in filling in the details. To determine one point it is necessary to have two bearings taken from different stations. It is advantageous to take a third, as a test of accuracy. Such points as the following should be plotted from intersections, if possible, viz.: cross-roads, marked changes in direction of the roads, where they enter villages, woods, or marshes, where they cross rivers, bends in the rivers, crests of small hills, some principal buildings in the villages, farm-houses, ferry-houses, bridges, and generally any conspicuous point that is recognizable from different stations. When a sufficient number of these have been fixed, so as to cover the ground well in every part of the survey, all is ready for sketching the details. The manner of accomplishing this is given in this chapter. In order to obtain the bearings to give the intersections above alluded to, the primary points may be occupied with a theodolite or compass; and if any important position has been overlooked, it may be assumed as a station, and be projected from the bearings of two or three visible primary points. If but one primary point is visible, its bearing and distance are sufficient to project the point.

Supplying details by a Plane Table.—The plane

table is put in position, in reference to the principal points, by a compass. The sheet already contains the projections of the primary, and such secondary points as have been determined. Details are obtained, either by intersections or by measurements of distances. For the various applications that may occur, reference may be made to the description of the plane table. It is sufficient to state, that, if two known points are visible, the position of the observer may be obtained; if no primary points are visible, his place may be obtained by measuring the distances to two known points. The measurement of distances is done in different manners, depending upon the degree of accuracy which it is necessary to obtain. For military purposes, pacing is generally applied.

The points which it is well to occupy, as stations, with the plane table, are those just enumerated under the head of secondary points. They are all determined by the methods just referred to.

The directions of the roads, as they leave any station, are noted and drawn in projection by the hand. They are represented by two parallel lines, nearer or farther apart, according to the character of the road. The width is exaggerated on the map, for effect; but it should be noted and recorded, to be mentioned in the memoir, if necessary.

From each station we pace off the distances to the surrounding details, take them off from the scale, and plot the points.

For distant or inaccessible points, we sight them, and draw pencil-marks on that part of the sheet where they are likely to fall; and then we leave the station.

We now proceed, say along the road several hundred paces, or to a point which it is desirable to occupy as a station, and fill in by the eye the intervening details. To this end, we pace the distances to the points, from which we are able to fix the corners of hedges, woods, bend in rivulets, etc.; or, if the adjacent stations of the plane table are within one hundred and fifty or two hundred yards, we may rely upon the eye alone and neglect the pacings. This, however, depends in some degree upon the skill of the sketcher.

The same process is pursued at each station, until the whole area has been included. No station should be left until all surrounding features have been obtained, and intersections obtained on points sighted from previous stations.

If, from any station, but a single point of the triangulation is visible, its direction should be drawn, for it serves to correct any error committed by inaccurate pacing; and generally, it may be said, no means of verification should be omitted.

Villages.—Take station at one of the outlets; fix it as before; then proceed towards a spire or chimney which enters in the primary triangulation. Stop at each street corner; plot the streets, and fill in the details of houses by the eye. Arrived at the primary

point, take a new direction and follow it till it leaves the village, and continue this process till the whole is completed.

Water-Courses.—It may be impossible to take station on a rivulet. When this is the case, follow a direction near its course, and from each station sight the bends, if visible, or any distinguishing points, as bluffs, trees, etc., and fix them by intersections. Having determined a sufficient number, join them, and we have the rivulet. If the stream has breadth appreciable on the scale, it would be well to follow one of the banks, and *intersect*, from different stations, any remarkable points on the other bank. If this is not practicable, pursue such a path as will enable you to *intersect* points on each bank.

Forests.—Make a circuit of the forest, occupying, as stations, the salient and re-entering points, as well as those where roads, streams, or ravines emerge. Fix them, and fill in the intervening parts. Then follow one of the roads or ravines to a central known point, if there be any such, and from that take another direction. In general terms, conform to the mode of procedure laid down for villages.

What has been said in reference to the surveys of villages, rivers, and forests, relates to the use of the plane table; but the guiding principles are the same for the compass, and it will not be necessary to repeat it.

The prismatic compass, although not so accurate as the plane table, is extremely serviceable, and permits

rapid progress. The sketch which is made may either be connected or in parts, which are to be combined subsequently. Both are here described.

A station is fixed by compass bearings to two or, better, three primary points, or by a bearing and a distance; thus, if but few primary points are determined, we have the means of fixing as many intervening points as may be desirable.

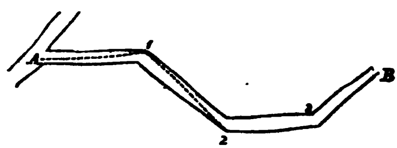


Fig. 48.

In following a tortuous stream or road, the work may be expedited by using the compass only at alternate stations. For instance, let A B represent a road starting from A, which, as well as B, has been determined from intersections; we take the bearing of 1, and plot the direction. Pace the distance to 1, and note it; then proceed immediately to 2, pacing the latter interval; at 2 take the bearing of 1, and also of the next station in advance; lay off the distance from A to 1, from the scale on the first direction plotted: this fixes 1; then from 1, plot the bearing of 1, as taken from 2; prolong the direction and lay off on it the distance 1.2. This gives 2, without occupying 1 as a station.

In Fig. 49 is given a representation of the usual method of keeping the field-book. The measured distances are recorded between the two parallel lines. The total distance between two stations is written

within a circumference traced about the position of the second station. Thus, in the figure, 650 is the distance between A and B. The bearing of the next station is recorded outside of these lines, with a line under it; thus, 280° is the bearing of C from B. In marching from A towards B, at the distance of 200, we cross a rivulet which comes from the left, and on the right, at the distance of 40, is the corner of a wall. Farther on, 400, the wall comes up to the line A B. In a similar way we may sketch the hedge, wood, etc.

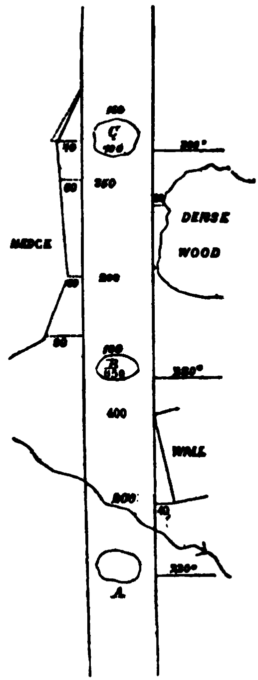


Fig. 49.

This gives a series of detached sketches, which are to be transferred to a general map afterwards. For determining each station, as B, C, etc., there are given a bearing and a distance. The details on either side are transferred according to the scale. The bearings of more distant points taken from A B C, etc., are plotted, and the intersections fix the positions.

If a connected sketch is desired, it is necessary to transfer to a sheet the positions of the primary points

in the vicinity of the ground to be sketched, and also any other points of importance whose positions have been determined. It is better to have as many points as possible. Draw upon the map the magnetic meridian and the scale, and provide a protractor and compass. Distances may be taken with a chain or by pacing. Proceed from one of the primary points to any other known point, measuring or estimating distances and filling in the details on either side, as in the last figure, and plotting all bearings taken, and so on, passing along such directions as enable one to work most rapidly. The method of intersections is used in connection with measurements.

If the known points are quite distant, a mile or two from each other, there is great room for the commission of error, particularly by an unskilful person. If, on the contrary, the points are near, we should feel more confidence in the work. Hence, after the location of the primary points, as many secondary points as possible should be plotted from intersections before the sketching of details, which we have just described, should be commenced.

Methods of determining the Azimuth of a Station, or the Direction of the Meridian.

We have seen that it is necessary to lay down the meridian upon the map. The magnetic needle indicates the direction of the magnetic meridian, which makes, with the true meridian, an angle which varies

from hour to hour, and from year to year, at the same place, and which generally changes from place to place. This angle is the variation of the compass.

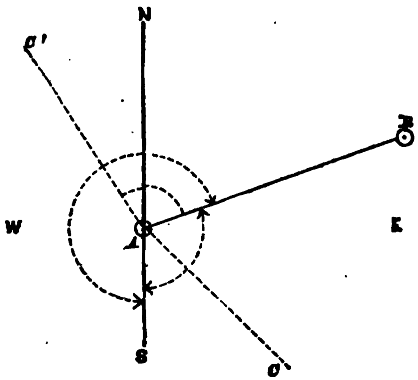


Fig. 50.

The direction of the true meridian must be determined from observation of some one of the heavenly bodies. Having laid down upon the map one of the lines of triangulation, we may draw the projection of the meridian, provided we know the angle between these two lines. For instance, Fig. 50, let A B represent the projection of the base, and N S the projection of the meridian. It is evident, if we know the angle N A B, that we may construct N S. The angle made by a vertical plane through A B, with the meridian through A, is called the azimuth of B. N S may be constructed when either of the four angles marked in the figure is given. It then becomes ne-

cessary to define the azimuth of a station, so that there shall be no ambiguity as to which of the four angles is referred to. It is usual to measure the azimuth from the south point of the meridian round by the west, so that the azimuth of B is equal to 180° + N A B. The azimuth of C′ is 180°—NAC′; of C, 360°—S A C′. When this system is not applied, the azimuth should be designated, so as to avoid error. Thus we may see the azimuth of a station is north 50° east, or S. 20° west, which avoids ambiguity.

There are both approximative and rigorous methods of determining azimuths, of which we now proceed to enumerate several:

1. The sun is on the meridian when it attains the maximum altitude. Bodies then cast shadows of minimum length, and if at this time we note the direction of the shadow of a vertical staff, this is the trace of the meridian on the ground. As the motion of the sun in altitude about this time is very slow, the changes in the length of the shadow will be found to be almost imperceptible for a few minutes, and as the direction of the shadow is changing all the time, we are left in doubt which to select. Hence this is a very rude method, and is only mentioned to introduce another. Three or four hours previous and subsequent to noon, the sun's motion in altitude is comparatively rapid; and if we mark the direction of the shadow when it has a given length in the morning, and again its direction when it has the same length in the after-

noon, and draw a line bisecting the angle between these two directions, it will represent the approximate projection of the meridian.

Thus, O A being the shadow of a style in the morning, when it terminates on the circumference, and O D being its position when it has the same length in the afternoon, N S, bisecting the angle A O D, is the meridian trace.

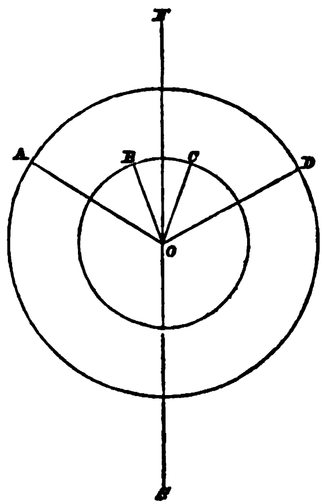


Fig. 51.

2. Another method is, to determine the trace of a vertical plane through the north star when it is on the meridian. It crosses the meridian at about the same time as a star, Alioth, easily recognizable, from Fig. 52, in the tail of the Great Bear. Then when this and the pole star are seen on the same vertical line, determined by a plumb-line, direct the telescope of a theodolite to the latter star, making it appear on the intersection of the cross wires. It will be necessary to place a faint light near the field glass, in order to illuminate the hairs. Clamp the instrument and let it remain till daylight, when the line may be staked out, if desira-

ble, or the angle made with the other station may be measured. Indeed, by using lanterns as signals, the line may be established in the night. The angle just measured is the azimuth measured from the *North*.

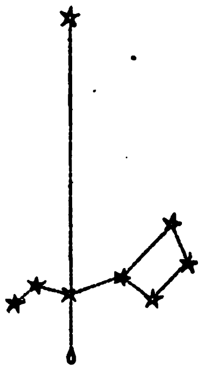


Fig. 52.

A better method is to use the north star, Polaris, when it is farthest from the meridian, whether to the east or west, when it is said to be at its greatest elongation.

The azimuth, A, of the star at this time measured from the north pole, is given by the formula: Sin. $A = \frac{\text{sin. P}}{\text{sin. L}}$, in which P is the polar distance of the star, and L the complement of the latitude of the place of observation. The azimuth applied to the horizontal angle between the star and the station gives the azimuth of the latter. To find the time of elongation, apply this rule. Add together the logarithmic tangent of the polar distance of the star and tangent of the latitude, and from the tables find the angle whose *cosine*

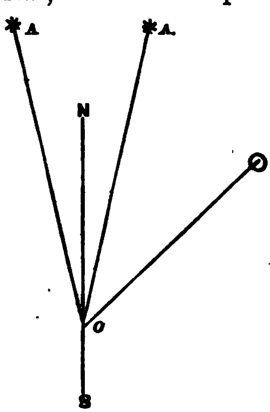


Fig. 53.

is equal to the sum. Divide this angle by fifteen, and add the quotient to the star's right ascension, the result is the *sidereal* time of the greatest western elongation: subtract for the time of greatest eastern elongation. A few minutes before this time arrives, with a theodolite, take the bearing of Polaris. A number of observations may be made, since the azimuth of the star is sensibly the same for some minutes. The star's polar distance and right ascension are found in the Nautical Almanac. This requires a chronometer, and a knowledge of the means of ascertaining its error in time, which is a problem in practical astronomy.

The following tables give nearly the times of elongation for different months in the year. The times are reckoned from mean noon, and suppose the watch of the observer to be without error:

EASTERN ELONGATIONS.

Days.	April.	May.	June.	July.	August.	Sept.
	H. M.	H. M.	H. M.	H. M.	H. M.	H. M.
1	18 18	16 26	14 24	12 20	10 16	8 20
7	17 56	16 03	14 00	11 55	9 53	7 58
13	17 34	15 40	13 35	11 31	9 30	7 36
19	17 12	15 17	13 10	11 07	9 08	7 15
25	16 49	14 53	12 45	10 43	8 45	6 53

WESTERN ELONGATIONS.

Days.	Oct.	Nov.	Dec.	Jan.	Feb.	March.
	H. M.	H. M.	H. M.	H. M.	H. M.	H. M.
1	18 18	16 22	14 19	12 02	9 50	8 01
7	17 56	15 59	13 53	11 36	9 26	7 38
13	17 34	15 35	13 27	11 10	9 02	7 16
19	17 12	15 10	13 00	10 44	8 39	6 54
25	16 49	14 45	12 34	10 18	8 16	6 33

The elongations are not given when they occur in daylight. Some of these tabulated times, however, occur before sunset or after sunrise, when the star is invisible through ordinary telescopes. By adding or subtracting five hours fifty-nine minutes to or from the tabulated times of elongation, we obtain the time that the star is on the meridian in the nighttime, when it can be observed. To repeat: When the time of elongation is nearly at hand, the theodolite is set up and prepared for observation. When the time arrives the star is made to appear on the intersection of the cross hairs, and the horizontal limb clamped. The instrument stands undisturbed till daylight, when the bearing of the star is read. The telescope is then directed to the station and the horizontal limb read again. The difference of the two readings applied to the azimuth of the star, calculated from the formula $\sin. A = \frac{\sin. P}{\sin. L}$, gives the azimuth of the station.

To find the variation of the compass, take the magnetic bearing of the station: the difference between it and the true bearing, obtained as above, is the variation, and is east when the north end of the needle is to the east of the true meridian.

At sea or on extended prairies, at the time of rising or setting of the sun, with the compass take the bearings of the two horizontal limbs: the half sum is the magnetic bearing of the centre. To determine the true bearing of the same point, we have the following rule:

Add to the sum of the complement of the latitude and the polar distance of the sun, its zenith distance, assumed to be 90° 33′ 37″: call the sum *D*, the polar distance P, and the co-latitude L. Then add together the logarithmic sine of D, the sine of (D − P); from the result subtract the sum of the sines of 90° 33′ 37″, and of L; divide the remainder by two, and find from the tables the angle whose cosine is equal to the quotient; multiply this angle by *two*, for the true bearing of the sun reckoned from the north meridian, to the east at sunrise, to west at sunset. The difference between this and the magnetic bearing of the centre, reckoned from the north magnetic meridian, is the variation of the compass.

CHAPTER VII.

ACCOUNT OF THE STEPS PURSUED IN THE REPRESENTATION OF THE RELIEF.

It has already been stated in chapter I. that, in order to obtain sufficient data for representing the relief of ground, it is usual first to determine, as accurately as possible, the elevations above some assumed plane of a number of points—as the crests and foot of the slope, the points where it changes inclination, etc.,—and then to complete the details by determining the horizontal sections, by more or less precise methods, depending upon the degree of accuracy which it is desirable to attain.

If we already know the altitudes of any prominent points above the level of the sea, starting from these we pass to elevations of other points above the same plane. If this is not the case, we may attribute to any point an arbitrary elevation, and deduce the altitudes of other points above the same plane.

These points are used as bases for levelling purposes, and hence should be determined with the greatest attainable accuracy, both in projection and elevation.

In order to show clearly how the difference of level may be obtained, let us refer to Fig. 54, where the altitude of A being known or assumed above the plane M N, it is required to find the altitude of B above the same plane.

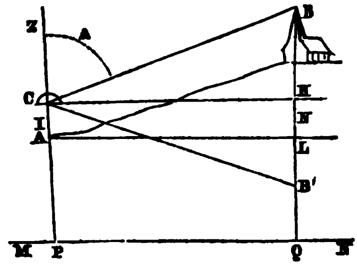


Fig. 54.

C H represents the horizon, and Z the zenith. The angle Δ is the zenith distance of the point B, as seen from C, which is the position of the theodolite, or other instrument used for the purpose. Let the angle Δ be measured, or its complement, the angle B C H, then from the right angled triangle we have

B H=C H tang. B C H=C H cotang.: Δ

B Q=B H+P C.

P C=P A+A C.

Hence the height of B above the plane M N becomes known.

If B′ had been the required point, then, measuring the angle B′ C H, we have:

B′ H=C H tang. B′ C H=C H cotang. C B′ H, and B′ Q=C P−B′ H. Hence it is necessary to know the horizontal distance between the stations and the vertical angle to determine the difference of level.

There are two corrections to be applied, however, when the distance between the stations is considera-

ble. The first results from the curvature of the earth, and has already been alluded to in the remarks on levelling; it is proportional to the square of the horizontal distance between the stations directly and inversely to the diameter of the earth; or denoting by L the difference of level, K the horizontal distance, and h' the height of the instrument above the station, then the difference of level corrected for the curvature of the earth is for A and B. $L = K \text{ cotang. } \Delta + h' + \frac{K^2}{2R}$, R representing the radius of the earth.

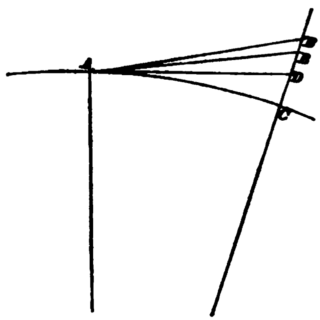


Fig. 55.

The second is refraction, by virtue of which the object is seen above its true place. This correction has been found to have an average value of $0.08 \frac{K^2}{R}$, and is subtractive.

In Fig. 55 the horizon of the observer at A is the tangent A D, and the object B is seen, on account of refraction, above its true place at some point, B′. Then the angle Δ is the zenith distance of B′ and K cotang. Δ is D B′, whereas the difference of level of A and B is C D. To obtain it, then, we have C B=D B′+C D−B B′= observed difference of level+correction for curvature −correction for refraction,

$L = K \text{ cotang.} \triangle + h' + \dfrac{K^2}{2R} - 0.08\dfrac{K^2}{R} = K \text{ cotang.} \triangle + h' + .42\ \dfrac{K^2}{R}$ (1) h' is positive when the instrument is above the station, and $\triangle$ is less than 90°; if $\triangle$ is greater than 90° h' is negative, and if the instrument is below, the station h' is negative when $\triangle$ is less than 90° and positive when greater.

CORRECTIONS FOR CURVATURE AND REFRACTION, IN OBTAINING THE DIFFERENCE OF LEVEL BETWEEN STATIONS, DISTANT FROM ONE HUNDRED YARDS TO THREE MILES.

Distances in yards.	Correction in feet.		
	For curvature.	For refraction.	For both curvature and refraction.
100	0.00215	0.00031	0.00184
150	0.00484	0.00069	0.00415
200	0.00861	0.00123	0.00738
300	0.01938	0.00227	0.01661
500	0.05383	0.00769	0.04614
650	0.09098	0.01300	0.07798
880	0.1668	0.0238	0.14300
1320	0.3752	0.0536	0.32160
1760	0.6670	0.0953	0.5717
2640	1.5008	0.2144	1.2864
3520	2.6680	0.3811	2.2869
4400	4.1688	0.5955	3.5733
5280	6.0030	0.8561	5.1469

A close approximation for curvature is given by the formula $\dfrac{2K^2}{B}$, K being the distance between the stations in miles.

The corrections above tabulated for ordinary practice in topography, are less than the probable errors of observations, and may be neglected. The table en-

ables every one to proceed intelligently, and if these corrections are not made the officer is at least aware of the amount of error thus committed. He should always apply them, however, when he is in search of accuracy with the best instruments.

The difference of level h' of the instrument and the station may be measured directly when it is practicable, or by a trigonometrical process when direct measurement is impracticable.

In Fig. 57 we select the points T, G, F, D, and I, assigning an arbitrary height to the steeple T, in which there happens to be a window some feet below the cross, which is the point observed. This height is measured, and the zenith distance of G is taken, which is the upper point of a chimney of a manufactory. It is to be understood that the altitude or depression may be taken instead of the zenith distance. Then going to G, we sight I and F; then occupying F, sight G, D, and I. From D we observe the vertical angles for F, T, and I. Finally, occupying I, we do the same for F and D. This method affords continual verification, and, as a test, we may conclude the height of T from that of D.

Applying the data just obtained in the formula (1), we deduce the respective differences of level between the assumed points.

We are now prepared to obtain the elevations of the important points of the ground, and for this purpose, dispensing with the corrections for refraction and

curvature, as our distances do not exceed 1,200 or 1,300 yards, the formula becomes L=K cotang. $\triangle + h'$.

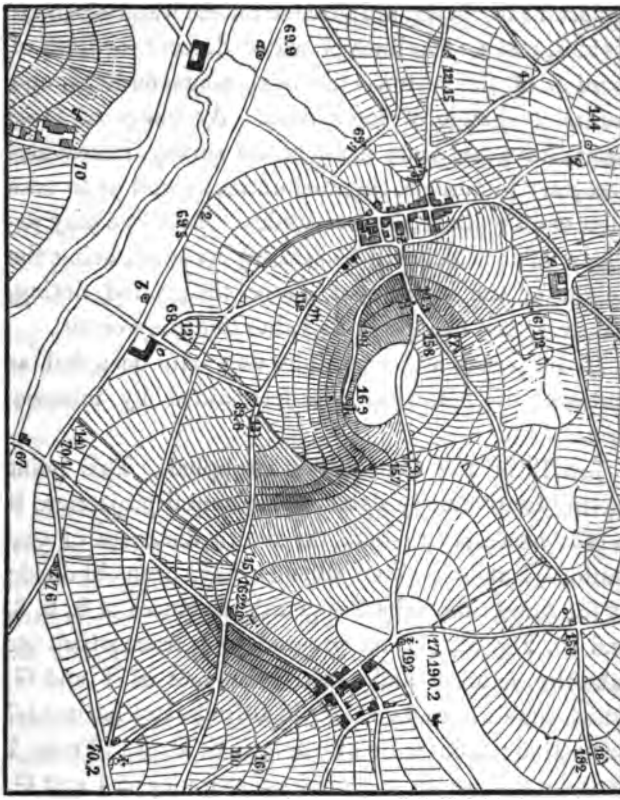


Fig. 56.

This value of L applied to the height of the station by subtraction when the station is above the point, and by

addition when below, gives the altitude of the point above the assumed plane.

As already stated, the points whose altitudes it is important to obtain, are situated on the water sheds or divides, and on the lines of water descent, or lines of reunion of the water,—the beginnings, endings, and points of change of inclination. As many of these points have not been fixed in the survey, it becomes necessary to measure their azimuths, as well as to take their zenith distances or altitudes. To h' we may assign a value which will be sensibly constant, being the height of the instrument above the ground, noting, however, any change in its value that may occur.

If the points are accessible, they are occupied as stations; if not, they are determined by intersections.

Let R be the first station occupied. This point having been already fixed in horizontal projection, it is only necessary to take the zenith distances of two stations, I and G, whose altitudes have been obtained; at the same time take the zenith distances of S, 2, 3, and 10, Fig. 56.. Then proceed to 4, from which we take the azimuth and zenith distances of T and G, which enable us to fix 4 both in altitude and horizontal projection; then we sight 3, 5, 6, S, P, R. From 7 we take the zenith distances or altitudes of I and G, and the azimuth of P, and then the azimuth and zenith distances of 5, 6, 8, 9, and 10.

Proceeding thus from point to point, we may obtain

the necessary observations, which are arranged in tabular form, as follows:

REGISTER OF LEVELLING OBSERVATIONS.

Stations.	Points Observed.	Azimuths.	Horizontal Distances.	Altitudes.	Heights.
R.	T.				
	G.				
	2.				
	3.				
	10.				
4.	T.				
	G.				
	3.				
	5. etc.				

The first three columns and the fifth are filled in on the ground. Afterwards, by the azimuths, the projections of the points are fixed on the map, and the distance taken from it and applied to the scale gives the data to fill the fourth.

Each point is, by these observations, determined twice, which insures accuracy and detects any errors. The two determinations should agree nearly.

This having been done, we take the map on the ground, for the purpose of sketching in the forms of the ground by the eye; or, in other words, to fill in horizontal curves, or to draw hachures to represent, in a

general way, the forms of the ground and the relative inclinations of the slopes.

To this end, we take positions on the water-sheds, and on the lines of reunion of the waters; in the first case the horizontals are convex, in the second concave. Without reference to equidistance, draw the curves or hachures, crowding the former together, or making the latter heavier when the slope becomes steeper, and acting inversely when the inclination becomes more gentle. These curves and hachures are provisional, and only intended to subserve a temporary purpose, and this being done, it is time to perform the final details.

From Fig. 56 it may be seen that the points whose altitudes we have determined are so distant from each other, that the lines obtained by joining them two and two do not lie throughout their length on the ground: hence we are not able to apply geometrical processes without the determination of other points; but we may apply an approximate method, which is generally sufficiently accurate for ordinary military surveys.

Join the known points on the same slope which gives profiles of the ground, and take the case of 14, 15, supposing the equidistance of the horizontal cutting planes to be ten yards.

The curve next above 14 is to have an altitude of 80. Draw it, by the eye, at a distance greater or less from 14, according as the provisional hachures or curves indicate a gentle or steeper slope. In a similar

way find the point of the curve 160, which is first below 15. We have yet to determine points on the curves whose altitudes are multiples of 10, between 80 and 160. If the provisional hachures are of equal lengths, the slope is uniform, and we divide the space from 80 to 160 into eight equal parts, and each point of division is a point of one of the required curves. When the hachures are shorter on one part of the profile than on another, we crowd the points of division together where the hachures are shortest. Taking up the other profiles in the same way, we determine other points, and then join the points of equal altitudes by curves, giving them the inflexion observed upon the ground, and represented on the map by the forms of the provisional curves, or the disposition of the hachures. The inflexions give an idea of the forms of the ground, and their proximity of the steepness.

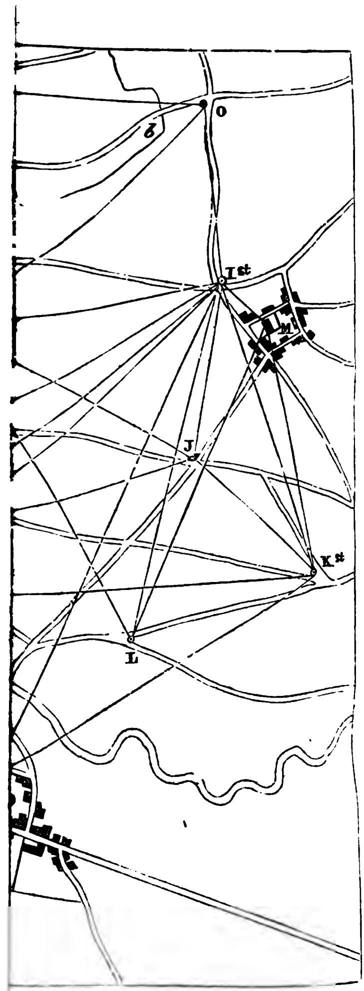
This method is followed in the military schools in France, and is well adapted to cultivate that topographical *coup d'œil* so important in duties of this character.

For an outline of a more accurate method, the reader is referred to chapter I.

With a spirit-level or water-level it is easy to trace the curves upon the ground. For this purpose clamp the vane on the level-staff, at a height just equal to the altitude of the line of sight above the ground; then send a man with it, and, by trial, let him find points where the middle of the vane is seen on the cross-

hairs; plant stakes at these points, which are evidently points of the horizontal curves. To find points of the curve one yard above, slide the vane down on the staff that distance, and, as before, determine points by trial. These points may easily be fixed by the compass or plane table in horizontal projection.

It has been supposed that the zenith distances or altitudes have been measured with a theodolite, or any instrument with a vertical graduated limb; while in surveys in the field, or any that it is essential to complete very quickly, we would use some one of the simpler instruments described in Chapter V, which give the tangent of the angle of elevation or depression directly, instead of the angle itself. The difference of level between two stations, in that case, would be the product of the horizontal distance between them by the measured tangent, this to be corrected for the height of the eye of the observer above the ground.


O
b
I st
M
J
K st
L

CHAPTER VIII.

AN EXAMPLE.

To illustrate the preceding principles, let it be supposed that Fig. 57 represents a plan of the survey. A reconnoissance of the ground indicates A B as a favorable base line, easily measured, and giving immediately, eligible triangles A B T, A B H, A B F, A B E. These points, E, F, T, H, and the vertices of the other triangles, are selected as principal points. They are well distributed over the ground, permit the employment of triangles of favorable form, and are points from which a good view of other stations and of all marked points in their neighborhood can be obtained. In order to decide upon these points, the officer visits them separately with a pocket sextant or compass, and from each takes the bearing of every other visible principal point. He may, if in doubt as to the propriety of adopting them, make a preliminary sketch. For this purpose, according to any suitable scale, he lays down upon the paper the base line A B, already measured; and having taken the magnetic bearing of B from A, he corrects it for the variation of the compass, and through A, by means of a protractor, lays off the meridian, making with A B the true bearing of

B. Taking the bearing of H, F, T, E, from A, and then from B taking the bearings of the same points, he is able to plot these points by intersections, and, by a protractor, measure the angles of the triangles A B H, etc., or, indeed, obtain them by taking the difference of their magnetic bearings. By plotting them, however, he may, by taking off in dividers the distance A H, etc., from the paper, and applying it to his scale of equal parts, find approximate values for the sides of the triangles.

If any primary point, as L, should not be marked by any distinguishing feature, as a tree or chimney, etc., he erects there a station or flag pole.

He embodies the results of his observations in a table of this form:

Stations.	P'nts obse'd	Magnetic Bearings.	Length of Sides.	Remarks.
			yards.	
A, Pine-tree at western extremity of base.	B	S 73° E	A B=1248.5	
	H	N 79 30′ E	A H=1470	
	T	N 47° E	A T=1137	
	etc.		A F=1025	
B, Eastern extremity of base, marked by a pyramidal station.	A	N 73° W	B H=1165	
	H	N 24° 30′ E	B T=1317	
	T	N 14° W		
H, Flag-pole on top of a conical hill.	A	S 79° 30′ W	H P=1289	
	B	S 24° 30′ W	H O=1597	
	P	N 32° W	etc.	
P, A steeple of a church.				

Each station having been occupied, and from it the useful bearings taken and recorded, and the approxi-

mate positions of the primary points laid upon the sketch, it is found that the points have been judiciously selected.

The base is carefully measured and remeasured by the chain, or, for greater accuracy, by other processes, which it is scarcely necessary to describe here, since the chain generally subserves military purposes sufficiently well. For this purpose, as previously stated, the different points of change of slope are marked by stakes, and the inclinations and lengths of the slopes measured by the chain and level, in conformity to principles laid down on page 16. Each of these lengths is reduced to the horizon, and the sum is the horizontal projection of A B.

We are now prepared to measure the angles. For this purpose, supposing the theodolite to be the measuring instrument, we set it up, adjust, and level it at B. The telescope is successively directed to each of the visible stations, and for each, the verniers of the horizontal and vertical limbs are read, and the angle recorded in tabular form as above.

By any of the methods for that purpose, the reading of the north meridian on the horizontal limb is ascertained, and the difference between this and the reading of A gives the azimuth of A, estimated from the north to the west. Let us suppose that difference to be 67° 25′; then, by referring to the compass bearing of A from B, we find it to be N. 73 W.; hence the variation of the compass is 73° − 67° 25′ = 5° 35′, and is

east, since the north end of the needle is east of the true meridian.

The vertical readings give the angles of elevation or depression of the different stations as seen from B, and serve to determine the difference of level of the primary points.

The difference between the instrumental readings of horizontal limb, when the telescope is directed to A and to H, is the angle A B H; between those of H and F is the angle H B F, and so on for all similar cases.

Having completed the observations at B, the theodolite is taken up and carried to A, which is a pine-tree, so that it is impossible to set it up exactly at the station, but an eligible position, A′, is found for it, from which all the primary points connected with A are visible, distant from A 9.4 yards. We will now give the calculation to reduce the measured angle, B A′ T, to the centre of the station, or, in other words, ascertain what the angle B A T would be, if it were possible to mount the theodolite over the centre of A. For this purpose the formula, page 115, is $A - A' =$

$$A\,A', \sin. \frac{(B\ A'\ T + A\ A'\ T)}{A\,B\ \ \sin.\ \ 1''} - \frac{A\,A', \sin.\ A\ A'\ T}{A\,T,\ \sin.\ \ 1''},$$

and our data are B A′ T, measured by the theodolite, $= 64° 12'$, and A A′ T, measured by the theodolite, $= 57' 29'$. A A′ calculated.

A T and A B, taken from the table of distances, given above, are respectively 1,137 and 1,248.5 yds.

Then for the first term we have,

Log. of A A′ 9.4	0.9731279
Log. sin. of (B A′ T + A A′ T) = 121° 41′	9.9299112
Log. of A B 1248.5 *A. C.*	6.9036115
Log. sin. of 1″ *A. C.*	5.3144251
Log. 1321″.5	3.1210757

For the calculation of the second term,

Log. of A A′ 9.4	0.9731279
Log. sin. of A A′ T 57° 29′	9.9259487
Log. of A T 1137 *A. C.*	6.9442395
Log. sin. 1″ *A. C.*	5.3144251
Log. 1438″	3.1577412

Hence $A - A' = 1321''.5 - 1438'' = -116''.5 = -1'56''5$ and $A = 64° 12' - 1'56''5 = 64° 10' 03''5$.

Whether the operation is to be performed, or whether the angle at the assumed point near the station is to be taken as the true angle at the station, depends upon the accuracy which it is expected to attain, and the distance from the station of the point assumed, as compared with the length of the sides of the primary triangulation.

The theodolite measuring horizontal angles, there is no correction for *reduction to the horizon* to be applied to them.

In the same manner the angles at each station are measured, and the triangulation is completed.

As stated in chapter I., we regard the extent of the

survey as plane; hence the triangles are plane, and the sum of the angles in each should be equal to 180°. If the work has been well done the difference will be slight, and unless there is reason to suppose the existence of error at any particular station, the difference between their sum and 180° is distributed equally among the angles, so as to make their corrected sum 180°.

We are now prepared to calculate the triangles, and to illustrate the process we will take the first one, A B T.

It is to be remarked, that these angles and sides have been assumed, to illustrate the application of principles, and have not been obtained from actual observation.

Angle B A T, 64° 10′
Angle B T A, 58° 45′
Angle A B T, 57° 05′
Side A B, 1248.5 yds.

The relation between the sides and the sines of the opposite angles gives:

Log. sine T 58° 45′ *A C*	0.0680787
Log. sine A 64° 10′	9.9542741
Log. A B 1248.5	3.0963885
Log. B T 1314.5	3.1187413

A similar computation gives the value of A T, and in each of the subsequent triangles there will be known, as we progress, one side, and all the angles from which the remaining sides result. These may be tabulated under a form like the following:

Triangles.	Reduced Angles.	Length of Sides.
A B T	B A D = 64° 10′	A B = 1248.5
	B T A = 58° 45′	B T = 1314.5
	A B T = 57° 05′	A T =
A B H	A B H =	B H =
	B A H =	A H =
	A H B =	

Having in this manner found all the angles and sides as well as the azimuth of one, we are prepared to lay down the principal points on the map. Then through B draw a line to represent the meridian, and another at right angles to it. The azimuth of A from B, measured from the north to west, we have found to be 67° 25′, and the length of A B 1248.5 : the co-ordinates of A then are—

$$\text{N.} \quad 1248.5 \times \text{cosine } 67^\circ\ 25'$$
$$\text{W.} = 1248.5 \times \text{sine } 67^\circ\ 25'.$$

Then, laying off from B towards the north a distance equal the first co-ordinate, and on the other co-ordinate axis a distance to the west equal to the other, and drawing through these points lines respectively parallel to the axes forming a rectangle, the intersection of these lines is the projection on the paper of A. A precisely similar course gives the co-ordinates all the principal points connected with B. For the co-ordinates of H, we have

$$\text{N} = \text{B H} \times \text{cosine } 30^\circ\ 05' \quad (\text{N B H})$$
$$\text{E} = \text{B H} \times \text{sine } 30^\circ\ 05'.$$

The co-ordinates of O we obtain by adding to the

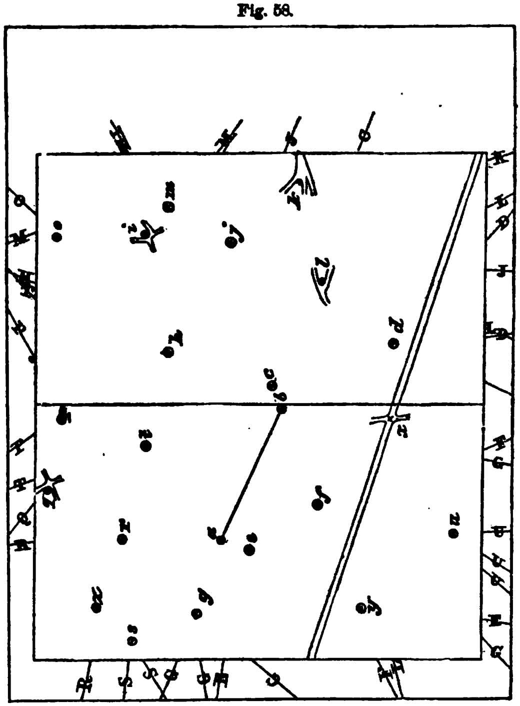
co-ordinates of H those of O in reference to H. Thus, for O we have

$N = BH \times \text{cosine } 30° \ 05' + HO \times \text{cosine of azimuth of O from H.}$

$E = BH \times \text{sine } 30° \ 05' + HO \times \text{sine of azimuth of O from H.}$

These elements should be recorded in tabular form. Then we may regard the principal points as plotted, and we have a configuration represented in Fig.

Fig. 58.



58, where the stations are designated by the small letters.

In order to avoid confusion, no mention has been made of the bearings taken from each of the stations to other features. Thus, from B may be seen a number of points on the banks of the river, easily recognizable, as the bends, a remarkable tree, also a number of cross-roads. These are sighted and their instrumental bearings recorded. From A some of the same points are visible; their readings are taken and recorded. F gives a new series, and so on for each of the stations. These give rise to a multitude of intersections, fixing the positions of the secondary points, and the same point is capable of being determined by more than one intersection generally.

Should there be any point from which only one primary station is visible, we determine it by taking the bearing and measuring the distance of the station, and the same plan may be followed for the details which adjoin any determined point.

Having fixed a cross-road with the compass, take the bearings of the branches as they radiate from this point, and plot them on the sheet.

Thus as many points are determined as the officer may choose, and the details about each are obtained.

The manner of obtaining the details has already been fully explained and needs no repetition.

The differences of level are also to be obtained, and, for the purpose of applying the formula, we will take

a single case. Let us suppose that, at the beginning, the height of each of the principal points is unknown. We assign to the clock-tower M, which is 4.3 below the cross, an arbitrary height of 130. With the theodolite we have measured the depression of D below M, = 9′ 10″; hence Δ is equal to 90° 09′ 10″; K=1237; $h=-4.3$.

$$\begin{array}{ll} \text{Log. K} & = 3.09237 \\ \text{Log. cot. } \Delta & = \underline{7.42657} \\ & \quad 0.51894 \end{array}$$

$$\begin{array}{r} =-3^{s}.3 \\ h=\underline{-4\ .3} \\ 7\ .6 \end{array}$$

Assumed height of M 130.

$$+.42\frac{K^2}{R} \qquad \underline{0.1}$$

$$\begin{array}{r} 130.10 \\ \underline{-7.60} \\ \text{Height of D} = 122.5 \end{array}$$

In the same way the altitudes of each of the points may be obtained. The details of levelling and location of the horizontal sections are completed by the means previously described.

CHAPTER IX.

IRREGULAR SURVEYING.

This branch of the subject relates to reconnoissances which it is necessary to execute very rapidly, either on account of the proximity of the enemy or from some other cause, and with special instruments, or frequently without any. It is needless to insist upon the utility of such surveys; it is sufficient to remark that they serve to regulate the march of troops, suffice for the selection and location of camps, field fortifications, the passages of rivers, etc.

These reconnoissances may be regarded as composed of two parts: 1. The topographical, to represent clearly details that a general map never affords; 2. Statistic and military memoirs. As to the latter, what is said elsewhere as to their preparation is general and applies to this case.

These rapid and irregular surveys having for their object to represent the natural and artificial features of the country, with the maximum exactitude consistent with the rapidity of their execution, it is evident that they are based upon the same principles as more elaborate operations. The difference between them consists in the use of more portable and less bulky

7*

instruments, in the substitution of pacing for the use of the chain—indeed, in the estimation of distances and details by the eye in many cases. It is then necessary to have had considerable experience in regular surveys in order to know the most simple mode of procedure, and to estimate the errors necessarily introduced.

The survey is commenced by the determination of the principal points by triangulation, to which details are afterwards referred. All, then, reduces to the measurement of angles and a base. This base may sometimes be taken from a general map, or obtained by the chain, or measuring by *pacing*.

When it is to be measured it is selected, if possible, on a high, open, level plain, where it is easy to measure it, so that from its extremities a large extent of ground may be seen. Then, by the smallest possible number of triangles, we pass to two points, occupying a central position and susceptible of serving as stations; from these stations we sight all the points that are of importance in fixing the details, the lines of sight intersecting on these points. Thus the number of triangles is increased, and their sides become shorter and shorter. These, in their turn, serve to determine a crowd of other points, and adjacent details may be easily filled in by the eye, or by pacing, without great errors.

The secondary points and the details should be almost entirely determined by intersections of lines

plotted from bearings. If the use of the chain over long distances affects a survey with considerable error, it may readily be conceived that they would become very great were all points to be fixed by measurements not more exact than are obtained by pacing, by the use of stadia or by estimation.

Still, measurements by pacing or otherwise are not to be entirely discarded ; a distance and a bearing to a station are sufficient to determine a point. In some cases no alternative is possible, and we are compelled to plot from measured distances.

The officer starting from a station, determined as prescribed above, walks along the side of one of the triangles and sketches, by the eye or by pacing, all the details to his right or left; or, if preferable, he may take any other direction, making an angle with one of the sides, which angle is to be measured and plotted immediately. Thus he fills in very quickly the area of the triangle. This method applies to all descriptions of country ; if open, it is of easy application ; in thickly wooded localities it is more difficult; but the method of measuring distances to every point should only be resorted to in the last extremity.

When the country is open, and the officer has men and time at his disposal, he may cause to be signalled, or marked, trees remarkable for their position or elevation ; then, by getting as far above the ground as he can, he determines each of the points which are to serve as stations and centres for the determination of

details, up to the middle point of the interval to the adjoining stations.

An elevation of three or four feet increases considerably the field of view, so that it may sometimes be advantageous to make observations from the saddle, for which purpose an instrument must be used which does not require a fixed support, such as the pocket sextant or prismatic compass. He will probably experience considerable difficulty in recognizing an object seen from different points of view and in different lights. He makes use of every thing to guide him, the form or color of the top of a tree, a point of rocks, a chimney, or even the smoke from it, if the chimney should cease to be visible. The time taken to fix well a good station cannot be considered as lost: it will be regained and compensated for by the rapidity with which he obtains the details in the interior of the triangles, and the certainty that he will have that his errors will be small and promptly rectified, from the frequency with which he encounters known points. Indeed, there may be economy of time, because he will sketch with the certainty that he will not be obliged to return to what was previously done, whereas by the method of measuring the distance of each point, he never draws a line but with the fear that he will be obliged to efface it to correct it, so that his work will be more quickly and more neatly done.

The country, however, may be of such a character that it is not possible to work otherwise than by meas-

urement of distances, with the disadvantages of but few and widely separated known points. The labor then becomes painful and tedious. It then becomes necessary to determine, with all possible care, the directions pursued, and their intersections, and to make continually excursions to the right and left, thus proceeding by a series of partial reconnoissances.

The French prefer the plane table for determination of points by intersections, as indeed generally in topography, both for accuracy and expedition. For this irregular purpose several authorities recommend the portable form described on page 84. It may be held in either hand, with a single staff for a support, elevating and depressing it alternately to point it, and the attached compass read.

Without a compass, the plane table may be approximately put in position, by fixing in it a needle upright, the shadows of which have been previously traced for every hour in the day. Then, to put it in position at any station, observe the time by a watch, and turn the instrument until the shadow of the needle corresponds to the time of day. This would not answer for *regular* topography; and is only practicable when the sun shines.

When an officer has no instruments, he can construct rude ones, which may serve a good purpose in measurement of angles. A protractor, the legs of a pair of dividers, a variable length held at a constant distance from the eye, for instance, at arm's length,

as described on page 87, or a triangle, the base a rule, and the other two sides of a thread, its extremities attached to the ends of the rule, which, being bent at different points, gives different angles between its branches. Take a sheet of paper, fold it into two parts, then double it again along the folded edge as though to divide it into four equal parts. The angle between the edge of the first fold and that of the second is assumed as a right angle. Cut off one of the pieces carefully along the fold, double this at the angle, so that the edges accurately coincide, we obtain 45°, and by successive bisections smaller angles. Then, marking along the folds with a pencil and numbering the angles, we have a protractor, either to plot or to measure angles.

Attaching a light plummet to the angular point, we may adapt it to the measurement of vertical angles, holding it vertically with the angular point from the eye when the object is above the horizon, and towards the eye when it is below.

For distances which we cannot pass over we may use the telescopic stadia, previously described, without the staff, which is replaced by a local object, such as a tree of a kind which has nearly a uniform height, a window, a cabin, man or animal, or any other object to which we can assign a height more or less conformable to the truth.

For other methods of rude approximation refer to Chapter IV., on Distances.

Vertical Measurements.—The elevations of different points are at least as important on some accounts as their projections, and are determined by a base and the angle of inclination, except when the eye may be trusted, and the former method may be used in connection with the latter.

After measuring an inclination, the height may be obtained by use of a triangular scale of the form of Fig. 41, where the base represents the trigonometrical base according to the scale; from the angular point N lines are drawn, making with the base, respectively, angles of 5°, 10°, 15°, etc. The perpendiculars through the points of division of the base complete a series of similar right-angled triangles, of which the altitudes multiplied by the denominator of the scale, by 10.000, if the scale be $\frac{1}{10.000}$, give the differences of level.

For further methods and instruments we may refer to Captain Livet's level, and Bernier's clisimeter, and Burel's reflecting level.

Sketch by the Eye.—It is often necessary to make a sketch of ground in the presence of the enemy. Here every thing is sacrificed to celerity. The officer is thrown upon his own resources, and has no longer even the simplest instruments. Hence, success depends upon rapidity and accuracy of *coup d'œil*, and here will be felt, in a marked degree, the value of experience. The less the officer is able to count upon

the exactness of his operations in fixing details, the more nearly should he conform to the order of procedure in other cases. He should, as before, form large triangles, the areas of which are to be filled in with details sketched in from each station. A little experience enables one to obtain considerable accuracy, by the following means: Having provided a light board or portfolio, with the paper stretched, lay down the base on it, according to the scale adopted. Then take post at one extremity of the base, and set up a needle on its projection. Hold the board horizontally in the left hand at the height of the eye, so that, looking along the line, we see the other extremity of the base, then the line is in the vertical plane of the base, and the board is in position. Move the eye so that the needle is seen projected on a point which it is desirable to fix, and, with a pencil in the right hand, draw a line from the pin towards the point, and in the same way sight other points. Then go to the other extremity of the base, and place the projection of the base in the vertical plane through the base, then the board is in position; and then sight the points seen from the first station, and draw lines as before; their respective intersections are the points required. The needle, of course, is shifted to the projection of the second station. The board is evidently applied as a plane table.

As for the relative heights of different points, the eye must be trusted, as well as for the character of

the different slopes. A straight rule, suspended by its centre of gravity, will be horizontal; and the eye, looking along it, will be able to ascertain what points are above, and what below the plane of his horizon, and the difference of level he should be able to estimate rudely.

It may be that the officer has not even time for these simple processes—that, indeed, he cannot halt at all; in such cases his sketch is made after his return. No precepts can be laid down for this case. The officer should be familiar with the forms assumed by different kinds of country, so that he may be able to make fair inferences in reference to points which are masked, from those which he is able to see; of course, he sees all that he can; measures distances between the most important points by the time required to pass over them—the direction of streams, ravines, etc.,—the slopes and elevations, kind of houses, etc.

Sketch made from verbal information from spies, or inhabitants of the country:

For instance, if an officer be ordered to conduct a detachment to a portion of the field of operations, of which no maps have ever been prepared, he first endeavors to obtain a definite conception of the character of the country, its roads, villages, farmhouses, etc.; for this purpose he interrogates spies, refugees, or others, who are familiar with it, and, after careful comparison of their answers, draws his inferences. It often requires tact to discover how much

reliance is to be placed in the various accounts. Some know more, and others less, than they pretend—the occupations of different persons lead them to take particular notice of different features. These hints are necessarily of a very general character. It is generally advantageous to make a sketch of the country in the presence of, and from the information of, the person or persons interrogated, and to mark upon it the distance between the remarkable points in *time*.

Even in this case it is often wise to have a system of triangulation of the principal points, laying them down by their conjectured distances apart, and using them as points of reference to determine the positions of farm-houses, bridges, cross-roads, etc.

It will be perceived that the spirit of the method is the same in all cases, whether it is a river, a road, or a position which is to be reconnoitred; whether it is to be thoroughly surveyed, or whether the work is to be done rapidly, the principles are the same in all. In the last-mentioned case, it is necessary to sacrifice some details to others and to celerity; and the points that deserve especial notice are determined by the instructions of the general and an acquaintance with the operations of war.

Itineraries.—These are special affairs intended to regulate the march and halting places of convoys, supply or emigrant trains. For these purposes it is exceedingly important to obtain reliable estimates of the resources of the country as to forage, provisions,

the camping-places, the quantity and quality of grass and water. It is more important, too, to have the distances between camping-places given in time than in miles. A table embodying these data, and others giving the facility of the roads, fords, etc., is an itinerary of the route, though it is usually accompanied by a map of the road and its vicinity. On the manner of making this, little can be added to what has gone before.

Distances are obtained by pacing, by the rate of travel of your horse, or, if you have a wagon, strap an odometer to one of the wheels. At the starting-point take the bearing of the direction of the road and of any objects, such as peculiar peaks, well-marked trees, houses, etc., which it may be desirable to include in the sketch, and read the odometer. When the road changes direction, take another bearing, and the distance; and, indeed, do the latter for all important points, such as where the road crosses a stream, where it commences a remarkable ascent or descent. The surrounding details are sketched, as the officer proceeds. The manner of doing this has been described. The note-book is kept in the form of Fig. 49. At the conclusion of each day's march, the partial sketches are transferred to the general sheet.

In reconnoissances of the character described in this chapter, considerable latitude exists in the signs or representations of different features; and while it is desirable that there should be uniformity, at the same

time it is only essential that they should be understood. In the next chapter will be found General Dufour's system of conventional signs, to be used for the results of a reconnoissance.

A recapitulation of the points of difference between a regular and an irregular survey, and a more exact account of the steps to be pursued in the latter operation, may be useful to some, even if wearisome to others.

It has been said that the instruments must be portable, such as can be carried in the pocket or satchel. This reduces us to the compass (prismatic or pocket), or the pocket sextant, for horizontal angles; and to Burel's level, or a protractor, or a small graduated strip, for vertical angles.

We pace the base, or we ride over it, noting the time, and thus calculate its length; we remeasure it, if possible, as it is important to get nearly its true length; we select it as nearly horizontal as possible, for there is no time to reduce it to the horizon, and we are obliged to accept its measured length as our base. There is no correction of angles for reduction to the horizon, or for reduction to the centre of the station, so that we accept the measured angles for our triangulation. The sextant's angles lie in the plane of the observer and the objects, hence are not horizontal, but, for small differences of level, do not differ much from their reduced value. Without reduction, they are more accurate than those given by the com-

pass; nor is there time to calculate the triangles, or to obtain the co-ordinates of the principal points. A line is drawn to represent the magnetic meridian, and with a protractor the base is laid down according to its bearing; and as the protractor does not lay down an angle perhaps within a half degree, we are less concerned that the compass is equally defective.

The protractor lays down the lines of sight first from one extremity of the base, then from the other; and the principal, as well as the secondary points are fixed by intersections. The sketch is then made; as the officer proceeds, he fills in by the eye, by estimating distances, or by pacing them, if he has time, of the details surrounding each station; and, as he proceeds from one to another, he notes in the same way all important points.

In such an affair almost every thing must depend upon the individual; his rapidity of conception and execution, his familiarity with the means at his disposal, his ability to estimate distances, to detect the direction of streams from the general features of the country; in a word, on the *coup d'œil* which, in its best development, is a natural gift carefully cultivated and enlightened by experience.

By experience a person becomes able to pace a distance within perhaps 1-30th, or, in some cases, within still narrower limits, and to estimate distances of two or three hundred yards or less, within 1-10th to 1-15th of their true value.

The points which require special attention depend upon the views of the commanding general, the object which he contemplated in ordering the reconnoissance, and which he has imparted, verbally or by written instructions, to the officer.

CHAPTER X.

GENERAL DUFOUR'S REMARKS ON RECONNOISSANCES.—EXAMPLES OF RECONNOISSANCE.

Reconnoissances may be classified as follows, viz.: reconnoissances in force, and topographical reconnoissances.

The first have for their object to ascertain the strength, composition, and position of the enemy's forces, as well as their movements, in order to enable the general to draw inferences in reference to their intention, or to plan an offensive movement. They are executed by a detachment of sufficient strength to drive in the enemy's outposts, and compel him to develop his strength and display his forces.

Topographical reconnoissances are not less important, for a general without an exact knowledge of the local features, cannot determine upon a plan of attack, or, indeed, undertake any operation of magnitude. He must know the various distances between certain points, in order to combine the marches of different columns; and the difficulties to be encountered, in order to decide upon the arrangements to be made, and the precautions to be observed. This information is obtained by special reconnoissances, for even the most

detailed maps are insufficient; they never tell the nature of the soil, the kind and condition of the roads, the state of the rivers and bridges, and other points of information which it is essential to be informed of before undertaking an operation.

This kind of reconnoissance is usually a function of staff officers. They are sent during peace to study the countries that may become theatres of operations, and to draw up descriptions of them, by means of topographical maps, if they are permitted; if not, by memoirs, at the same time making note of any errors that they are able to discover in existing charts. It is the staff officer, too, who, protected by a few troops, usually makes, in the presence of the enemy, the sketches which represent, with more or less exactness, the most essential features of a position. They, too, usually prepare the itineraries as the army advances, survey positions, battle-fields, and often large extents of country. However, every officer is liable to be placed in circumstances which make it necessary for him to explore a locality, and to give a description of it. For this reason, it may be well to indicate the means which can be employed by one who is not an expert draughtsman.

The most difficult feature to represent in a map is the relief of the ground. It is done, either by constructing the projections of the curves cut out of the ground by equidistant planes, or by hachures. The latter mode requires a degree of skill which is not generally pos-

sessed by officers; and, moreover, it frequently happens that there is not time. For this reason it is proposed to replace hachures by lines, which simply indicate the contours, one at the top and the other at the foot of the declivity. These are not necessarily lines of level, but they are the lines most readily seized by the

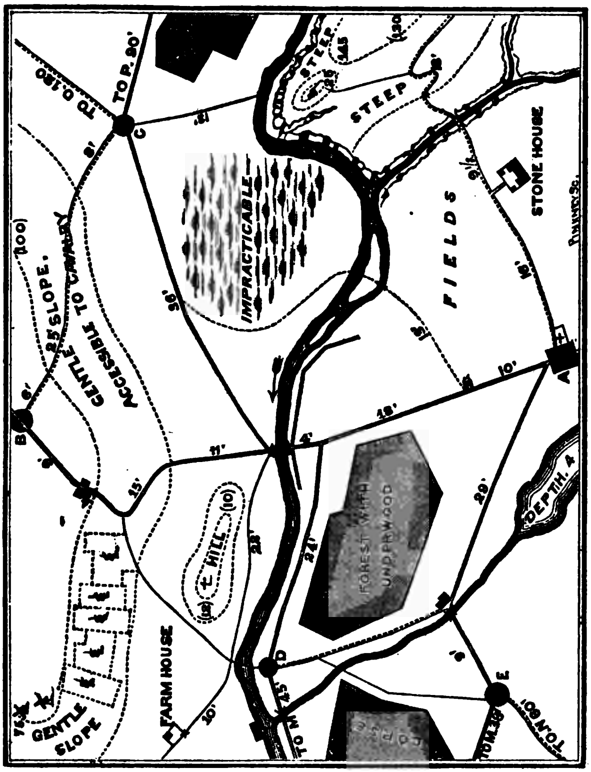


Fig. 59.

eye, and, moreover, are the most natural ones to be made when the officer has no time for a more detailed representation, or when he merely desires to indicate the general form of a plateau, hill, or range. The space between these lines is sufficient to contain a few words descriptive of the circumstances of the slope. We can record that the inclination is gentle or rapid, that it is practicable for cavalry or not, and state the approximate height. We may thus clearly and briefly state all that it is essential to know. In order that these contour lines may not be confounded with those intended for other purposes, they should be traced in dotted lines, as in Fig. 59. In the upper part of the figure, the contour lines indicate a plateau which rises gently from the plain. Lower, and near the river, there are two others, which indicate an elongated eminence; and words or figures between the curves, make known the character of the slopes, or at least what is essential in a military point of view. On the right is a spur, represented in a similar manner; it terminates near the river, in abrupt rocky bluffs, and a little hill, which rises at its extremity, is indicated by its own special contour lines. The figures in brackets are the heights of the points of the upper curve above the corresponding points of the lower. These elevations are only approximative.

Thus the plateau is, on the right, about 100 feet above the plain, its centre about 90, and the left about 75. The isolated eminence is 10 feet at one extremity,

and 12 at the other above the plain, and so on for the others. It is not easy to estimate altitudes by the eye, and hence they are rarely represented in a sketch; but the figure and explanation show how to present this information without confusing the map. Every officer using this simple mode of representation, ought to be able to indicate, with more or less accuracy, the forms of the ground which he passes over. The fidelity of his sketch will depend only upon the accuracy of his *coup d'œil*, a faculty only acquired by experience, and the officer need no longer be delayed by the difficulty and duration of this part of the work.

General Dufour further proposes to substitute for the usual topographical signs, in such cases, simpler modes of representation.

First, for *water-courses*. Represent them by two lines, one stronger than the other; or by a succession of parallel lines between the two bounding ones. A blue tint may be used to replace the interior lines; an arrow represents the direction of the current; a water-mill is represented on the lower part of the river. The rivulet on the right of the figure is enclosed by steep bluffs, as is shown by the two irregular lines traced along its banks.

Means of Crossing.—On the left is a ferry-boat; in the centre is a stone bridge, distinguished from the wooden one, over the rivulet, by the fact, that the latter is narrower and has no wings on the approaches. Higher up, a ford is indicated by dotted lines. This

line need not be confounded with contour lines, both because of its position and the manner in which it is drawn. Lakes, ponds, etc., are represented by the same means as running water, the only difference being in the form. Marshes are designated by a contour line, within which are groups of short parallel lines, with an occasional representation of grass. We note, within the outline, whether it is practicable or not.

Forests require much time by the ordinary conventional signs. It is sufficient to trace their outline, and in the interior draw parallel right lines across, to represent trees, and a winding line for vines. In the interior write the kind of forest, whether open or tangled, large or small timber. Rocks are difficult of representation; as their forms are extremely variable. It is necessary to imitate them. When they are in the form of long bluffs, we may be content with sketching the top and bottom line, as in the right-hand part of the figure, putting a few cross lines to relieve it from the appearance of being a band.

Houses.—If it were necessary to fill in all the houses of a town, as would be proper in a thorough survey, it would require much time, and would discourage the greater number of officers. But it is extremely easy to mark their place by a sign, without concerning ourselves with their form. A circle, crossed by parallel lines, denotes a village. For more important towns, use a square similarly marked.

Isolated houses, such as farm-houses, churches, etc.,

are drawn without reference to any scale, to represent their proper shapes.

Roads.—It is necessary to exaggerate their dimensions in order to represent them. A great route of communication is represented by two parallel lines; the same answers for a carriage road, only the latter is narrower. A road practicable for small vehicles only, is represented by a full and dotted line, and trails for pack animals by a single full line. Distances between designated points are marked in the roads. They are expressed in the time required for a footman to pass over them, supposing him to travel at a certain rate; the gait of a horse might be applied to the same purpose. When a road extends beyond the limit of the sheet, the name of the place to which it leads should be written on its line of direction.

Levees and dikes should be represented, since they may be of military importance in defence. They are represented by parallel lines; and to be distinguished from roads, they are crossed transversely by short hachures. One is represented in the figure, near the bridge.

Such are the conventional signs which an officer may employ to represent easily and rapidly the result of his observations. He may not make a fine drawing, but a military sketch which may be very useful if the relative distances and the forms of objects have been passably obtained. To complete the sketch, the meridian should be laid down with more or less accuracy, and a scale of yards or miles, and fractions,

should be added; and as distances have been given in time, there should also be a scale of this kind.

An officer, charged with a reconnoissance, prepares his paper beforehand; glues it to a board, so that the wind shall not interfere; places his scales on it, and locates approximatively the villages comprised in the country to be reconnoitred, in such a manner, however, that they may be effaced. He fixes them by taking them from a general map, or from information derived from individuals. With this skeleton he is prepared to go to work.

Let it be supposed that the enemy's patrols have shown themselves in the country, and that it is necessary to provide for them. The officer arrives with his detachment at the village A, in the evening. He sleeps there, and acquires from intelligent inhabitants all possible information in reference to the surrounding country. He has already ascertained the number of inhabitants of the villages B, C, D, and E, the distances between them, and to the places connected with them by roads. He knows that, besides the bridge on the macadamized road, there is a ferry at the village D, and a ford above, practicable for cavalry. He has recorded these items, and, in addition, secured a good guide before retiring for the night. The enemy has been observed on the heights, on the right bank, and every precaution is taken by the officer to guard against surprise during the night.

In the morning he assembles his party at the break

of day, and sends a small detachment, under command of a subaltern or non-commissioned officer, to reconnoitre the villages D and E, and to discover whether they are occupied by the enemy. He dispatches another party, by the right-hand road, to examine the large country seat, and explore the ravine and the banks of the river. These detachments have orders to rejoin the main party near the bridge. The latter puts itself in motion, preceded by a small advance guard. A halt of a half hour is made at the inn on the main road, to give time for the detached parties to complete their duties, and to ascertain the character of the ford. He sends a man to examine and sound it. He then starts again, noting distances by his watch, and traces their directions on his map. At the bridge another halt is made, to await the junction of the detachments. They having joined, he leaves one-third of his force as a guard for the bridge, and with the remainder marches directly for the village B, throwing out skirmishers on the front and flanks, directing them not to lose sight of the main body. He continues to take distances and to sketch in the features of the country. He marks in his sketch the points where roads and trails leave the main route, the foot and summit of hills, the position of houses, etc. In reference to hilly portions of the road, he should diminish the length of scale, corresponding to a minute and more as the slope becomes steeper, for two reasons: first, that the horizontal distances, which

are the ones required, are less than the actual inclined portions passed over; and, secondly, because the actual distance passed over in the same time is less than it would have been on level ground.

The lengths of the scales should be reduced by one-fourth for gentle slopes, and by a third to one-half for steeper ones. When the eye is practised in the estimation of distances, it is of great advantage in such cases.

Arrived at B, the officer leaves a third of his force, and with the remainder advances a mile or two on the high road, to assure himself that no enemy is approaching from that route. He may at any time have an engagement with parties of the enemy. If he meets a patrol, inferior in strength to his own, or an outpost, he may attack, endeavoring to secure one or more prisoners, from whom he can ascertain the positions of the troops most advanced. After having thus beaten up the country he falls back promptly to the village B, and now, properly speaking, begins his topographical work. He establishes the main portion of his force in position at the village, to be prepared for an attack from the enemy, and, accompanied by a guard of a non-commissioned officer and two or three soldiers, and preceded by a few skirmishers, proceeds first to the left of the plateau towards the windmills, to note the slopes and sketch the country on this side. He makes the circuit of the plateau, returning by the post-house (indicated by a trumpet).

From B he proceeds towards C, taking half his force with him, directing the commander of the other half to leave the village in one hour and take a position at the foot of the slope of the plateau. Then proceeding towards C, he halts at the foot and top of the slope, to mark their directions on the sketch. He takes care to put in the lines he passes over by their bearings and distances taken from his scale. At C he ascertains the points to which the two roads lead and the distance of the nearest villages. He traces the roads on his sketch and records the name and distances. He follows the path to the river, passing through the woods, and returns to the village, which enables him to fix the principal bend of the stream.

From the village two men start, to make the attempt to cross the marsh and reach the ford. Being unable to succeed, they return and so report, and if the officer places confidence in their statements he marks the marsh impracticable; if he has reason to distrust their report he examines it for himself, if he has time. From C the detachment returns to the bridge by the road, the officer detaches two men to make the circuit of the marsh, and, after crossing the ford, to return to A. He estimates by the eye the distance of the foot of the small hill and traces the curve on his sheet.

He then makes the circuit of the small hill, following the foot of the slopes and the paths, then ascends it, where he obtains a good view of the form of the river

which he sketches. He then proceeds to the farm, measuring distances and plotting them, returning to the bridge by the path, which enables him to examine the ferry and to fix the mill on the river-bank.

His whole force is now united between the bridge and the hills, where it remains for an hour yet, while the officer, with a guide and a party of four or five men, visits the villages D and E. After the expiration of the hour his force returns to A and awaits the arrival of the officer, who sketches the woods, land, and stream, as well as the directions of the roads which set out from D and E.

If the day is not too nearly exhausted, and he is confident that the enemy will not interfere with him, he may leave his party at A, and, escorted by two or three of his best soldiers, proceed to the high ground on the right. From the chateau on the sugar-loaf hill he is able to see perfectly the whole course of the river, and can correct his sketch, if any correction is necessary. He follows along the ridge, up the steep bluffs, sketching them, and puts in the contour lines of the mountain, after an inspection of the ground. He returns along the rivulet and the river, and measures the length of the dike. His reconnoissance is now terminated, and, upon his return to camp, he finishes his sketch.

This sketch, made in such a hurried manner, doubtless contains large errors, but it expresses what is most essential in a simple and clear manner, and the

general will be able to ascertain from it, as well as from a more exact map, what it most concerns him to know.

The sketch may be left in pencil, as made upon the ground, or traced in India or common ink.

When the work can be divided among several officers it is, of course, done more promptly. An officer of superior rank superintends the whole. He occupies himself chiefly in providing for the safety of his command and in studying the general form of the country. He stations himself on elevated points, from which he obtains a good view of the ground to be sketched and of that occupied by the enemy.

The preceding remarks are General Dufour's, and are introduced because they expose, in detail, the mode of procedure in a particular case. The value of the sketch will depend very materially upon the circumstance, that the positions of the villages are taken from a general map. They are, in fact, the primary points. If their positions are unknown, it would be much preferable to fix them by triangulation, using the distance from A to the bridge for a base. After constructing by intersections the projections of the villages, the old chateau, the country house, bridge, farm, and summit of the hill near the ferry, etc., the method given above might be advantageously followed.

DUBLIN, *January* 5, 1846.

Having been requested by the editors of the *Aide-Mémoire* to give you a specimen of the sort of sketch

of a position required during the Peninsular war, with an account of the mode of performing the work, the annexed, which I was required to make by his Grace the Duke of Wellington, in Spain, is supplied accordingly, and the following is a statement of the circumstances under which that sketch was ordered, and the way I took to perform it:

In 1812, when the French army, under Marshal Marmont, was crossing the Tormes at Huerta, above Salamanca, before the forts of that place were taken, the duke, at that time standing on the high ground in front of Cabrerizos, observing the enemy, desired me to cross the river, and see what sort of a position there was, in a certain assigned direction, for stopping the advance of the French, and to make a sketch of it as quickly as possible.

There were about two miles to ride to the ford of station Sta. Marta, and perceiving at once that point would be the left of the position, on having crossed, I began at the point A. (Plate I.)

A.—The lines of direction to B, C, D, E, F, G were first laid down, sketching in the river, the roads, the village, and particularly the church of S. Marta. These lines of direction were, in fact, so many angles laid down and protracted on the sketch, but no instrument was used, as there was no time; every thing was done by the eye. I did not dismount—and galloped from station to station.

C.—Having finished at A, I went along the road

to Huerta (C), a farm of only two or three buildings, which was the only point to be seen in that direction from A. Judging then this distance galloped over, the line from the Church of S. Marta to C was assumed as a base.

It was desirable that this part of the sketch towards Huerta should be done first, as the enemy's skirmishers were exchanging shots with ours between C and (M) Pelobraro when I reached that ground.

C being fixed, the lines to H, I, J, K, L, M were laid off. The line H intersecting the line B, showed where the rivulet joined the Tormes. The line J intersecting A E, showed nearly where the steep fall of ground at J would come. The line L pointed out where the road to Calvarosa Abajo crossed the rivulet, and to that point, N, I went.

N.—Here the angle between Santa Marta and C was laid off, which fixed it, and then, intersecting the lines I and K (taken from C), those two farms were fixed. The direction, O, of the stream was noted, and also the line to J was intersected; also a fresh object, P, a remarkable tree, was taken, as it was along the crest of what would obviously be the position.

Q.—The village, M, could not be seen; I therefore went to the rising ground, Q, from whence it was visible. At this point it was observable that I was in a line with the farm K and Santa Marta church. Then, assuming that line to be correct, the angle between Santa Marta and C was laid down, which thus fixed

Q. The next angle was between C and M, by which the village, M, was fixed.

P.—Proceeding from Q up the hill to P, the angle was taken, formed by N and Santa Marta, which fixed P. It was also noticed that the line to the farm, I, passed to the right of the farm K, which observation helped to correct the sketch; also it could be seen that the line to H passed over K. The direction J was next taken, showing the fall of ground and the direction of the road D. There were no other points that could be fixed between D and the skirt of the wood, R.

R.—I then galloped to the top of the hill, and placing myself in a line with the two farms, I and K, that line was assumed to be correct; and then observing the angles between K and Santa Marta, and K and C and K, and P—R was fixed.

At R I could see over the trees the village of Calvarosa Arriba, and also a chapel, called Hermita, on this side of it, the directions to which were taken; also to the remarkable hill, S, and the abrupt slopes of the ground to the rear, U and V.

A line was drawn to the fall or gap in the ground, T, taking great care that this, as well as those to S, to Calvarosa, and the chapel, were as correct as possible in regard to the line from P, because the connection of the right of the position rested on this point, and the accuracy of the winding up of the sketch would depend upon the accuracy with which those angles were taken.

T.—Next to T, and as on reaching it it was clear that none of the points on the left of the position could be seen, except R, it became necessary that the distance from R to T should be judged as accurately as possible; which distance became a fresh base. At T, thus fixed, all the right could be seen, and the Hermita could be intersected as well as the ground to the rear (W, V, and E). The direction (X) of the smaller hill was taken, and the line over its summit, it was observed, passed to the abrupt right-hand slope of the ground W to the rear of the position. A farm also, in a hollow of some wood to the front, was also noted.

X.—I then went to the smaller hill, intending to go to the top, but the rocks were so rugged that I could not ride up, and so, standing on a line between it and T, at X, that station was fixed by observing the direction to E and the Hermita.

The line to Calvarosa from R was next intersected, which fixed that place. The direction to the houses, Z, was also laid down, and this place turned out to be the village of Arapiles, and the two remarkable hills were the celebrated hills of the same name.

The line W being intersected gave the boundary of the grand Y; the farm in front observed from T could no longer be seen. Passing then down by the right and along the hollow by the two great hills, I went to the Hermita, and this point having been before fixed, from thence the direction of the further fall of the great hill S and the slopes of the hill on the further

side of the Calvarosa valley were secured, as well as the direction of the water-course above and below. I then passed down the valley, and wound up the sketch at O.

Going back from thence to C, I proceeded along the main road to D and E, putting in, on judgment, the village of Carrajosa as well as the point F, where was a house, and where the great Salamanca road passed.

I returned to Cabrerizos, finding the duke where I had left him, and handed him the sketch, having been absent two hours and a half. I made a verbal report to his Grace, pointing out the high hill S, which we could plainly see from the spot where we stood, observing that it was doubtful how far guns could be brought there, not having had time to ride thither.

The duke gave me back the sketch to put it in ink, which I did, etc., etc. R. J. N.

These examples are given not to be implicitly followed, but to show that it is possible for one who is not a skilful draftsman to make a rapid sketch without instruments, which shall represent clearly the important local features. They are instructive, too, as they bring before the mind the difficulties which may be encountered in an operation of this kind, and suggest the nature of the demands that may at any time be made on the faculties of an officer.

APPENDIX.

Rules for the Resolution of Plane Triangles.

THE remaining elements of a triangle may be found when three are known, provided one of them is a side.

The following combinations may exist:

1. Let two angles and one side be known, or two sides and the angle opposite one. Designating the angles A, B, C, and the opposite sides by a, b, c.

$$\text{Sin. A} : \text{sin. B} : \text{sin. C} :: a : b : c. \qquad (1)$$

2. Knowing two sides a and b and included angle C.

$$\text{Tang. } \tfrac{1}{2}\,(\text{A}-\text{B}) = \text{Cotang. } \tfrac{1}{2}\ \text{C}\ \frac{a-b}{a+b}. \qquad (2)$$

This formula gives $\frac{1}{2}$ difference of the angles; their half sum is equal to $90° - \frac{1}{2}$ C. Add together the half sum and half difference, the result is A. Subtract the half difference from the half sum, the remainder is B: the third side results from formula (1).

3. Given the three sides a, b, c.

Represent $a+b+c$ by $2p$. Then,

$$\text{Sin A} = \pm\frac{2}{b\,c}\sqrt{p\,(p-a)\,(p-b)\,(p-c)} \qquad (3)$$

$$\text{Sin. } \tfrac{1}{2} \text{ A} = \pm\sqrt{\frac{(p-b)\,(p-c)}{b\,c}} \qquad (4)$$

$$\text{Cos. } \tfrac{1}{2} \text{ A} = \pm\sqrt{\frac{p\,(p-a)}{b\,c}} \qquad (5)$$

$$\text{Tang. } \tfrac{1}{2} = \pm\sqrt{\frac{(p-b)(p-c)}{p\,(p-a)}} \qquad (6)$$

Either of these formulas makes known the angles.

Area of a triangle whose sides a, b, and c are known.

Let p, as before, represent $\frac{1}{2}\,(a+b+c)$ and S the area.

$$\text{S} = \sqrt{p\,(p-a)\,(p-b)\,(p-c)}.$$

If the triangle be right angled, a the base and h the altitude. Then,

$$\text{S} = \tfrac{1}{2}\,(a\,h).$$

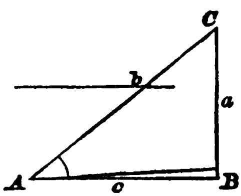


Fig. 60.

Let A B C be a right angled triangle, B being the right angle. Then,

$$\text{Sin. A} = \frac{a}{b} = \text{cos. C.}$$

$$\text{Cos. A} = \frac{c}{b} = \text{sin. C.}$$

$$\text{Tang. A} = \frac{a}{c} = \text{cotang. C.}$$

Several Problems Resolvable with the Sextant.

To find the distance of an accessible point from one that is inaccessible. To find A X, X being inaccessible. Erect A B perpendicular to A X; find a point, C, where the angle, subtended by the distance A X, is 45°. Then the triangle being isosceles, A C=A X. If, on any account, it is impossible to measure A C, draw C G perpendicular to C X, produce it to G where it intersects A X produced, then A G=A X. If A G cannot be measured, while C G can, $A\,X = \frac{C\,G}{\sqrt{2}}$.

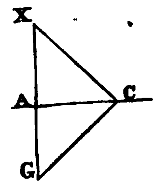


Fig. 61.

If it is impossible either to measure, or to go but a very short distance either to the right, left, or rear:

At A draw A B perpendicular to A X, and through B draw B C perpendicular to B X, measure carefully A B and A C, then $A\,X = \frac{\overline{A\,B}^2}{A\,C}$.

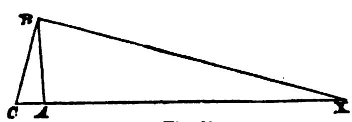


Fig. 62.

A slight error in either A B or A C will make a greater one in A X, but still the method may be useful, say, to determine the distance from a battery to a point on which it is to open fire.

To draw a horizontal through a given point. Plant an inclined stake, B O, and from its summit

suspend a plumb bob. Set the sextant at 90°, and from O look towards the bob, and send a man in the

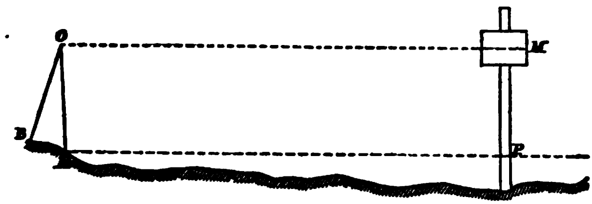


Fig. 63.

required direction with a level-staff, and let him move the vane till its middle line is seen on the bob, then O M is horizontal; subtracting O A from M N, it follows that P A is also horizontal.

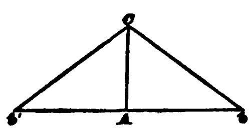


Fig. 64.

To erect a perpendicular to a given line, A B at A, measure from A in each direction on A B and its prolongation equal distances of a few feet, A b and A b'. Take a cord, longer than the sum of these distances, and fasten its extremities at b and b', seize it by the middle point, and draw it out, until the two branches C b and C b' are tense: C then is a point of the required perpendicular through A.

To construct an angle of 60°, mark the cord off into three equal parts, join its extremities, and fasten each of the points of division, and make of it an equilateral triangle. Each angle is 60°, and the angle which either side prolonged makes, with the one adjacent, is 120°.

Having measured a base line, A B, to find the position of C with a chain. From A measure A D and A E in the directions given in the figure, measure D E. From B measure the three distances B H, B G, and G H. On the paper lay down the line A B, according to the scale, and also A E and B G; with A as a centre, and A D taken from the scale as a radius, describe an arc of a circumference; with E as a centre and E D as a radius, describe an arc; their intersection is the projection of D. A similar process gives H in projection. Draw A D and produce it; where it intersects B H produced is C.

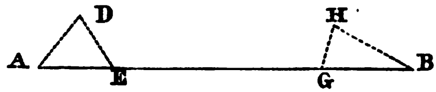


Fig. 65.

Trigonometrical Problems.

To determine A B when B is not accessible, measure the distance A C and the angles A and C, 180°— their sum is B. Then we have $A\,B = A\,C\,\frac{\sin.\,C}{\sin.\,B}$. To obtain the angle A without a compass, lay off on A B any distance A *b*, and an equal distance A *c* on A C, join *b* and *c* and measure it, then sin. A *b* sin. $\frac{1}{2}$ A= $\frac{O\,b}{A\,B}$. Reduce this fraction to its simplest form, and

go with it to the table of natural sines and find the number of degrees corresponding to it. If $\frac{\mathrm{O}\,b}{\mathrm{A\,B}}=4$, then $\frac{1}{2}$ A is equal to 24°, and A equal to 48°.

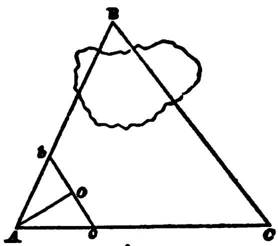


Fig. 66.

Again: Lay off on paper A C, according to any assumed scale. By any method lay off A B and A C, making the measured angles respectively with A C. Their intersection gives B, and A B in yards may be taken from the scale.

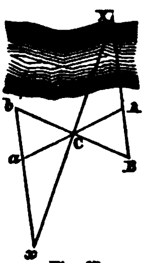


Fig. 67.

To find A X, prolong it to B; make B C equal to b C, and A C equal to C a; produce $a\,b$ and C X till they intersect in x, then $a\,x$=A X.

With an instrument for measuring angles make A C=C a, and the angle C $a\,x$=a A X, draw C X and $a\,x$.

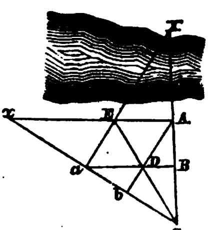


Fig. 68.

Again: Produce A X to C, making A B=B C, and each equal to C b and $b\,a$. Draw C a, and produce it; draw C A, a X, and C D, producing the latter to E; draw A E and produce it to intersect C a then A X=$a\,x$.

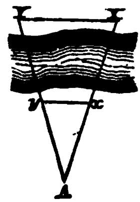


Fig. 69.

When the distance between two inaccessible points, X and Y, is required, determine A X and A Y by one of the preceding methods, and lay off on these lines respectively distances equal to $^1/_n$ of their lengths, then, Fig. 69, $x\ y = {}^1/_n$ X Y; or lay off on their prolongations distances equal to A X and A Y respectively, then $x\ y =$ X Y.

TABLE OF NATURAL SINES, COSINES, TANGENTS, COTANGENTS, SECANTS, AND COSECANTS, FROM 1° TO 90°.

Deg.	Sines.	Cosines.	Tangents.	Cotangents	Secants.	Cosecants.	Deg.
0	0.00000	1.00000	0.00000	Infinite.	1.00000	Infinite.	90
1	0.01745	0.99985	0.01745	57.2900	1.00015	57.2987	89
2	0.03490	0.99939	0.03492	28.6363	1.00061	28.6537	88
3	0.05234	0.99863	0.05241	19.0811	1.00137	19.1073	87
4	0.06976	0.99756	0.06993	14.3007	1.00244	14.3356	86
5	0.08716	0.99619	0.08749	11.4301	1.00382	11.4737	85
6	0.10452	0.99452	0.10510	9.51236	1.00551	9.56677	84
7	0.12187	0.99255	0.12278	8.14435	1.00751	8.20551	83
8	0.13917	0.99027	0.14054	7.11537	1.00983	7.18530	82
9	0.15643	0.98769	0.15838	6.31375	1.01246	6.39245	81
10	0.17365	0.98481	0.17633	5.67128	1.01543	5.75877	80
11	0.19081	0.98163	0.19438	5.14455	1.01872	5.24084	79
12	0.20791	0.97815	0.21256	4.70463	1.02234	4.80973	78
13	0.22495	0.97437	0.23087	4.33148	1.02630	4.44541	77
14	0.24192	0.97030	0.24933	4.01078	1.03061	4.13356	76
15	0.25882	0.96593	0.26795	3.73205	1.03528	3.86370	75
16	0.27564	0.96126	0.28675	3.48741	1.04030	3.62796	74
17	0.29237	0.95630	0.30573	3.27085	1.04569	3.42030	73
18	0.30902	0.95106	0.32492	3.07768	1.05146	3.23607	72
19	0.32557	0.94552	0.34433	2.90421	1.05762	3.07155	71
20	0.34202	0.93969	0.36397	2.74748	1.06418	2.92380	70
21	0.35837	0.93358	0.38386	2.60509	1.07114	2.79043	69
22	0.37461	0.92718	0.40403	2.47509	1.07853	2.66947	68
23	0.39073	0.92050	0.42447	2.35585	1.08636	2.55930	67
24	0.40674	0.91355	0.44523	2.24604	1.09464	2.45859	66
25	0.42262	0.90631	0.46631	2.14451	1.10338	2.36620	65
Deg.	Cosines.	Sines.	Cotangents	Tangents.	Cosecants.	Secants.	Deg.

TABLE OF NATURAL SINES, ETC.—*(continued)*.

Deg.	Sines.	Cosines.	Tangents.	Cotangents	Secants.	Cosecants.	Deg.
26	0.43837	0.89879	0.48773	2.05030	1.11260	2.28177	64
27	0.45399	0.89101	0.50952	1.96261	1.12233	2.20269	63
28	0.46947	0.88295	0.53171	1.88073	1.13257	2.13005	62
29	0.48481	0.87462	0.55431	1.80405	1.14335	2.06266	61
30	0.50000	0.86603	0.57735	1.73205	1.15470	2.00000	60
31	0.51504	0.85717	0.60086	1.66428	1.16663	1.94160	59
32	0.52922	0.84805	0.62487	1.60033	1.17918	1.88708	58
33	0.54464	0.83867	0.64941	1.53986	1.19236	1.83608	57
34	0.55919	0.82904	0.67451	1.48256	1.20622	1.78829	56
35	0.57358	0.81915	0.70021	1.42815	1.22077	1.74345	55
36	0.58778	0.80902	0.72654	1.37638	1.23607	1.70130	54
37	0.60181	0.79863	0.75355	1.32704	1.25214	1.66164	53
38	0.61566	0.78801	0.78129	1.27994	1.26902	1.62427	52
39	0.62932	0.77715	0.80978	1.23490	1.28676	1.58902	51
40	0.64279	0.76604	0.83918	1.19175	1.30541	1.55572	50
41	0.65606	0.75471	0.86929	1.15037	1.32501	1.52425	49
42	0.66913	0.74314	0.90040	1.11061	1.34563	1.49448	48
43	0.68200	0.73135	0.93251	1.07237	1.36733	1.46628	47
44	0.69466	0.71934	0.96569	1.03553	1.39016	1.43956	46
45	0.70711	0.70711	1.00000	1.00000	1.41421	1.41421	45
Deg.	Cosines.	Sines.	Cotangents	Tangents.	Cosecants.	Secants.	Deg.

These elements are calculated for radius = 1. For any other radius, multiply the tabulated element by the radius. To take out the sine of 24°, find 24 in the left column, and look in the column *headed* Sines opposite to 24°. Thus it is 0.40674. The sine of 60° is 0.86603. Find 60 in the right-hand column, run along the horizontal line to the column *footed* Sines, and headed Cosines, and find the proper number.

An element corresponding to any number of degrees and a fraction, is approximately found from proportion, using the next previous and succeeding whole degree. Thus the tangent for 10° 25′. The tangent for 10° is 0.17633; for 11°, is 0.19438. The proportion is 60′ : 25′ as 19438 − 17633 is to the number which added to 0.17633 gives the tangent required.

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